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# DEVELOPMENT OF AN INTEGRATED, ZERO-G PNEUMATIC TRANSPORTER/ROTATING-PADDLE INCINERATOR/CATAYLTIC AFTERBURNER SUBSYSTEM FOR PROCESSING HUMAN WASTES ON BOARD SPACECRAFT

Integrated Subsystem Performance Summary Report

By S. F. Fields, L. J. Labak, and R. J. Honegger

June 1974



Prepared under Contract No. NAS 2-6386 by

GENERAL AMERICAN RESEARCH DIVISION

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Niles, Illinois

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION



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## FOREWORD

This report summarizes the results of design, fabrication, and testing of a baseline laboratory prototype of an integrated, zero-g dry incineration subsystem for processing human wastes on board spacecraft. The work was conducted for the Ames Research Center of the National Aeronautics and Space Administration, under Task II of Contract No. NAS 2-6386, by the General American Research Division of the General American Transportation Corporation during the period April 1974 to June 1974 (GARD Project No. 1523).

The NASA Technical Monitor was Dr. Phillip D. Quattrone, Chief of the Environmental Control Research Branch; the program was comonitored by Dr. John Manning of Stanford University under a NASA University Consortium. Personnel in the Environmental Controls Systems Department at GARD performed the activities: Mr. Philip A. Saigh served as Program Manager and Dr. Stephen F. Fields served as Project Engineer. Messrs. Lawrence J. Labak and Robert J. Honegger participated in the designing, fabrication, and testing of the subsystem. Mr. Edwin K. Krug assisted in the testing and performed the chemical analyses of the end products.

ABSTRACT

A program was performed to develop a baseline laboratory prototype of an integrated, six-man, zero-g subsystem for processing human wastes on board spacecraft. The program included the development of an operational specification for the baseline subsystem, followed by design and fabrication of the subsystem.

The program was concluded by performing a series of six tests over a period of two weeks to evaluate the performance of the subsystem. The results of the tests were satisfacotry; however, several changes in the design of the subsystem are required before completely satisfactory performance can be achieved.

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# INTRODUCTION AND SUMMARY

## 1.1 Introduction

In the overall operation of manned spacecraft, proper management of wastes is essential to sustaining life within the closed spacecraft environment. Several factors influence the selection of a spacecraft waste management system, but foremost among these are crew safety and, in particular, system and end-product sterility. Also, the waste management system must be crew-acceptable both with respect to operation and man-system contact; it should be self-regulating and easily controllable with a minimum of crew participation, designed such that minor repairs or corrections can be readily carried out, and based on well-established physical, chemical, and biological principles. Finally, the system must be reliable and its use psychologically acceptable.

Of the various systems that have been contemplated for treating spacecraft wastes, the dry incineration system appears to be most suitable for the following reasons:

1. All end products -- water, ash, and gases -- are safe and permanently sterile, with no capability to provide or support biological growth or to support combustion.
2. All wastes from the bodily metabolic and elimination processes and from spacecraft housekeeping can be transformed to usable and/or storable products that are psychologically acceptable with no odor or disagreeable appearance. Product storage for indefinite periods is possible, and accidental leakage or spillage at any time into the cabin presents minimal safety or health hazards to crew members.

3. The basic dry incineration process is simple in principle and safe, with operations occurring at essentially ambient pressure and controlled temperatures up to 650°C (1200°F).
4. The weight of the solid ash after dry incineration is 5-10% of the original weight of the wet wastes. Product water is of a purity suitable, if needed, for recycling to the basic spacecraft water recovery system. Also, product gases -- oxygen, nitrogen, and carbon dioxide -- are suitable for direct return to the cabin atmosphere for partial make-up of overboard leakage or for storage and possible use in spacecraft control and/or propulsion systems.

The need for power to heat the incinerator, for an oxidant gas, and for a mechanically operating system appear to be compensated for by the above desirable system characteristics.

Since the dry incineration process produces sterile, innocuous, and conveniently managed end products, and since it lends itself to the development of a safe, esthetically acceptable system, it has been subjected to considerable investigation by the General American Research Division. Basic concepts and principles of human waste incineration for spacecraft use have been defined and a prototype incineration unit has been fabricated and successfully tested.

Under a previous NASA Contract, No. NAS 2-4438 (GARD Project 1437), testing and evaluation were conducted on microwave treatment and incineration of human feces, with characterization of the effluent products.[1*] Subsequently, under Contract No. NAS 2-5442 (GARD Project 1493), an experimental study was performed on the dry incineration of human fecal matter and urine distillate residue, and a prototype hardware incinerator was constructed and tested. The

* Superscript numbers denote references which may be found on page 45.

effects on dry incineration of operating pressure, oxygen concentration, power input, sample configuration, and catalytic oxidation of gaseous products were evaluated; and the concentration, identity, and sterility of liquid, gaseous, and solid end products were established.[2]

The four-man prototype, dry incineration system developed under Contract No. NAS 2-5442 did not require manual handling of the wastes, but it did entail manual handling of a waste-filled incinerator/canister. Since no manual handling of any type was desired, Contract No. NAS 2-6386 was awarded for the development of an automatic, zero-g waste transport subsystem that would transfer human and nonhuman wastes from a collection site to an incineration unit on board spacecraft. Concurrently, the need arose for greater system capacity to accommodate six men instead of four.

Contract No. NAS 2-6386 (GARD Project 1523) initially consisted of seven phases (A-G) and included development and in-depth testing of additional components and subsystems to provide a totally integrated waste management system. A study of the autoclave method of waste treatment was included in the program, since this technique appeared to be applicable to short-duration space flights.

The waste transport system developed early in the program utilized pneumatic drag to collect and transfer waste materials from a commode to an incineration unit. Since pneumatic waste transport was being utilized in other waste management systems for spacecraft, and since dry incineration with catalytic afterburning was a viable technique for treating human wastes on board spacecraft, the need existed to adequately develop and characterize, in detail, the technologies associated with these processes. To accomplish this objective, the activities under Phases A-G were modified in October 1973, and the program was divided into four major tasks:

Task I -- Development of Subsystem Components

Task II -- Development of an Integrated Subsystem

Task III -- Evaluation of an Autoclave Waste Management System

Task IV -- Documentation

Task I was concerned with the technology development and prototype hardware design and testing of a particle size reduction mechanism, a pneumatic waste transport system, a rotating-paddle incinerator, and a catalytic afterburner for processing human wastes on board spacecraft. A summary of all activities performed under this task may be found in Reference 3.

The activities performed under Task II were concerned with the technology characterization and prototype hardware development of an integrated waste management subsystem to provide a suitable basis for flight system trade-off studies,flight hardware design, etc., including the effects of zero-gravity operation; a subsystem was formed by integrating the four major components developed and characterized in Task I. This report documents the results of testing of this integrated subsystem. It also includes the operational specification and design drawings for the integrated subsystem (see Appendices A and B).

The objectives of Task III were to:

1. Adequately evaluate a waste management system based on the autoclaving method of sterilization,
2. Analyze the system to determine optimum design requirements, and
3. Compare the optimized autoclave system with other spacecraft waste management systems.

The results of this task are presently being summarized in a separate report.

## 1.2 Summary

The baseline integrated waste incineration subsystem is designed to convert, on a cyclic basis, the typical daily waste load from six men into innocuous, sterile end products. The subsystem is designed to provide pneumatic transport of the wastes through a waste transport tube to an incineration unit for retainment and size reduction through the action of a rotating paddle arrangement, and eventual conversion to vapors, gases, and an inorganic ash.

Conversion of the wastes in the incinerator takes place in three steps: (1) boil-off of volatiles and water by heating from ambient temperature through 100°C (212°F), (2) pyrolysis (thermal destruction in the absence of oxygen) of the dehydrated residue by heating from 100°C (212°F) to 540°C (1000°F), and (3) final combustion with oxygen of the carbonaceous pyrolysis residue at 540°C (1000°F) to 650°C (1200°F).

The generated gases and vapors pass through a catalytic afterburner for further processing with oxygen and then through a condenser for collection of all condensible vapors. The final inorganic ash is removed from the incinerator to storage by reverse air flow through the incinerator into an ash collector.

Under Task II, an operational specification for the baseline subsystem was developed (see Appendix A) and translated into detailed design drawings (see Appendix B). After fabrication and assembly, a preliminary check-out test and a series of five tests were conducted in the laboratory to investigate the performance of the baseline subsystem.

The results of these tests indicated the need for several changes in the design of the subsystem. These design changes include an increase in the motor power available to rotate the paddle blade assembly, relocation of the transport air blower, the addition of a technique of filtering particulates from the incinerator exhaust, and the addition of a technique of cooling the catalytic afterburner during pyrolysis.

The results of the analyses of the output products generated during the test series compare favorably with similar results documented in Reference 2. Oxygen consumption per gram of waste solids was approximately one gram, or twice the value reported in Reference 2.

On the basis of power and energy consumption figures for the test series, the required daily energy consumption by the subsystem is estimated to be approximately 2 kwhr per man.

## Section 2

## DESCRIPTION OF LABORATORY TESTING

### 2.1 Laboratory Test Setup

A schematic of the laboratory test setup for the baseline subsystem is shown in Figure 1. Primary components in the subsystem included a waste transport tube, rotating-paddle incinerator, catalytic afterburner, and oxygen controller. For a full description of these components, the reader is referred to Appendices A and B.

Photographs of the rotating-paddle incinerator are shown in Figures 2 and 3, the transport tube plug/seal in Figure 4, and the catalytic afterburner in Figure 5. The assembled baseline subsystem is shown mounted in its support frame in Figure 6. (This support frame allowed the subsystem to be operated with the incinerator axis of rotation either vertical or horizontal.) The main control panel is shown in Figure 7.

The laboratory condenser arrangement consisted of three separate condenser lines in parallel. Each condenser line passed through two cold-water condensate traps in series and then a dry ice-acetone condensate trap to insure removal of all condensible vapors. Output gases from this condenser arrangement were ducted into a gas collection envelope (a five-foot diameter mylar balloon).

The rotameters shown in the photograph of the main control panel (Figure 7) were used simply to monitor oxygen flow rates to the incinerator and catalytic afterburner and the flow rate of carbon dioxide through the bearing housing to the incinerator. The actual quantities of oxygen delivered to the incinerator and catalytic afterburner were measured separately with wet test meters, while the quantity of carbon dioxide delivered was measured with a Sprague meter.

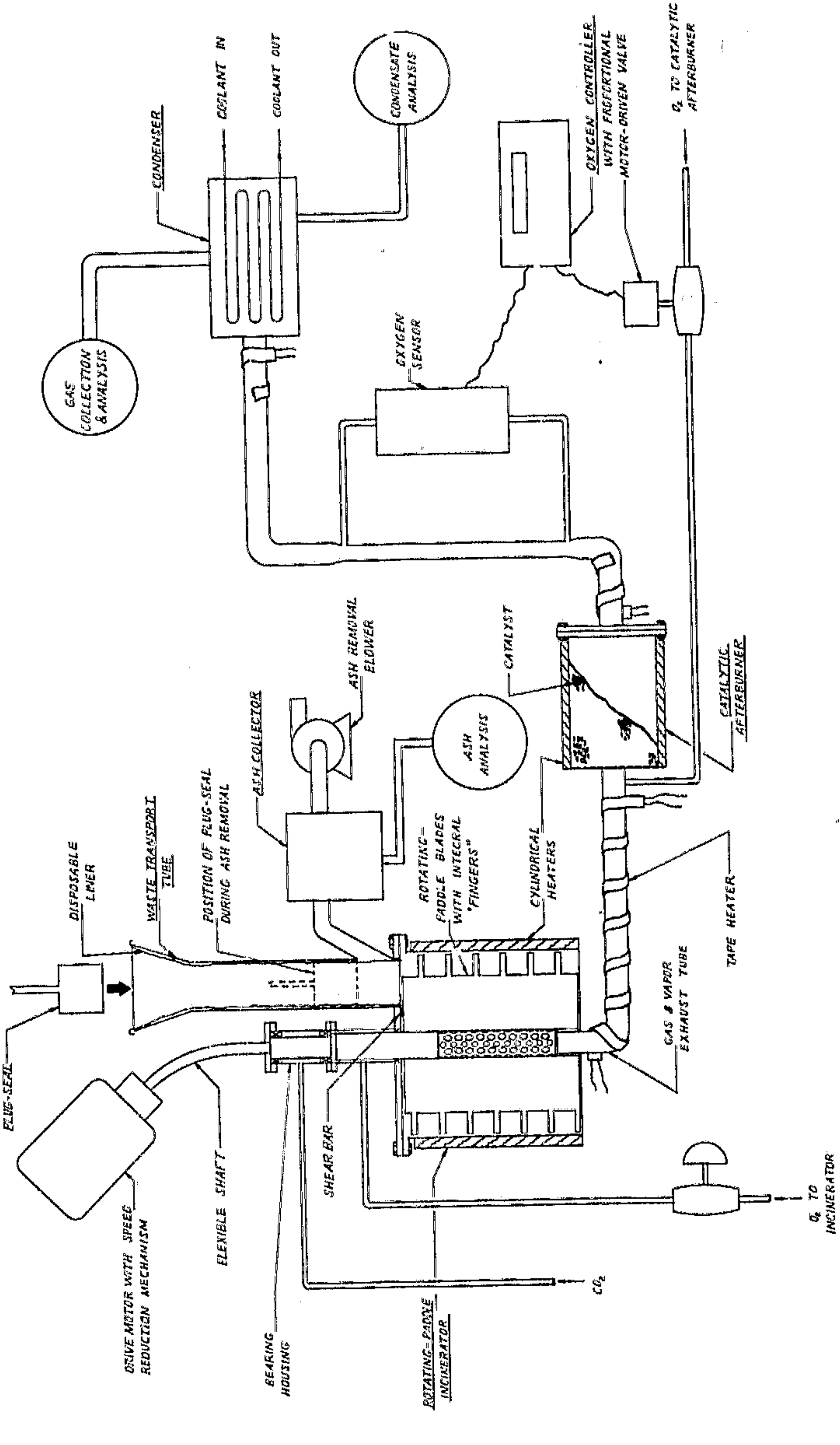


Figure 1 BASELINE INTEGRATED WASTE INCINERATION SUBSYSTEM - SCHEMATIC OF LABORATORY TEST SETUP

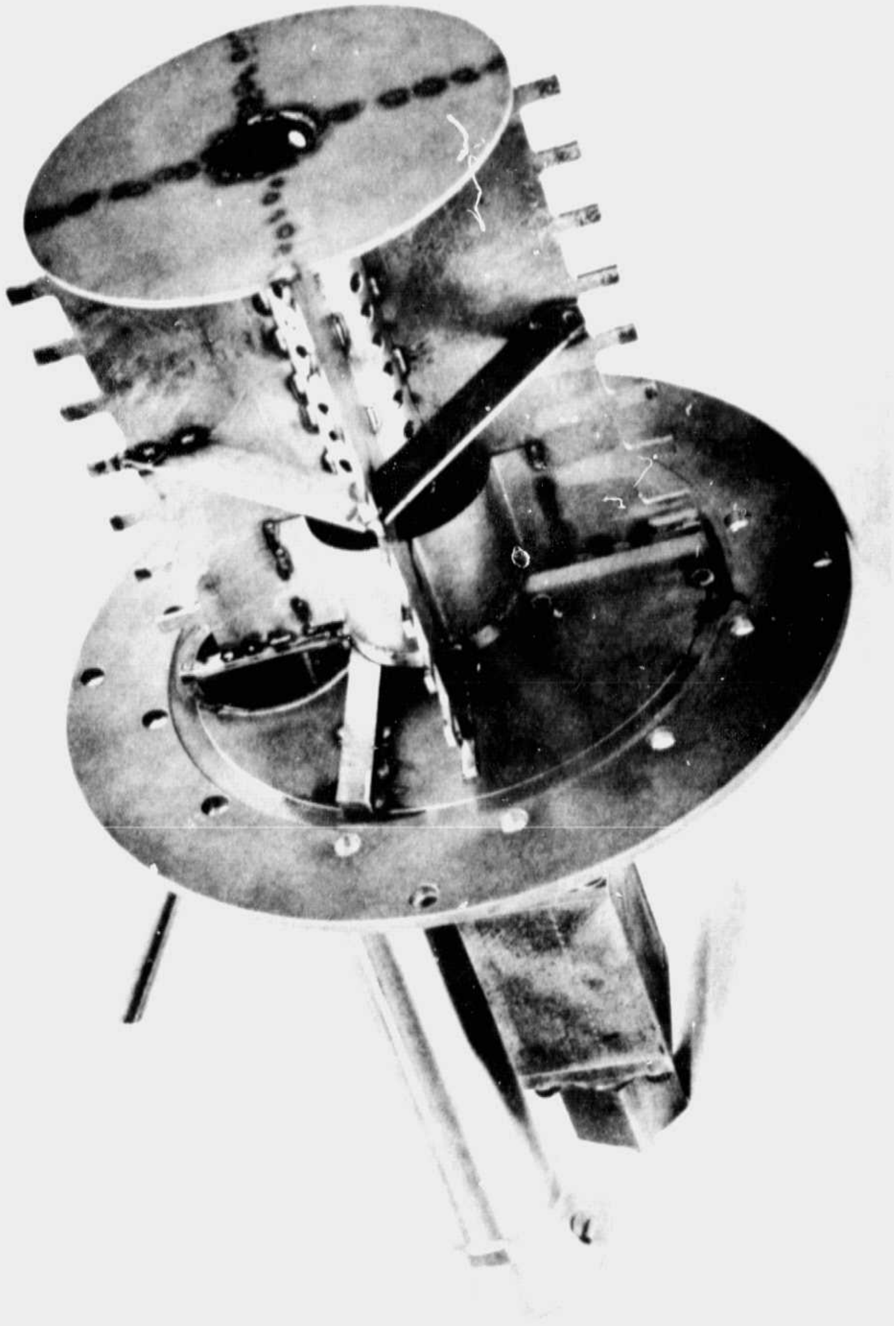

Figure 2 ROTATING-PADDLE INCINERATOR - SHELL REMOVED

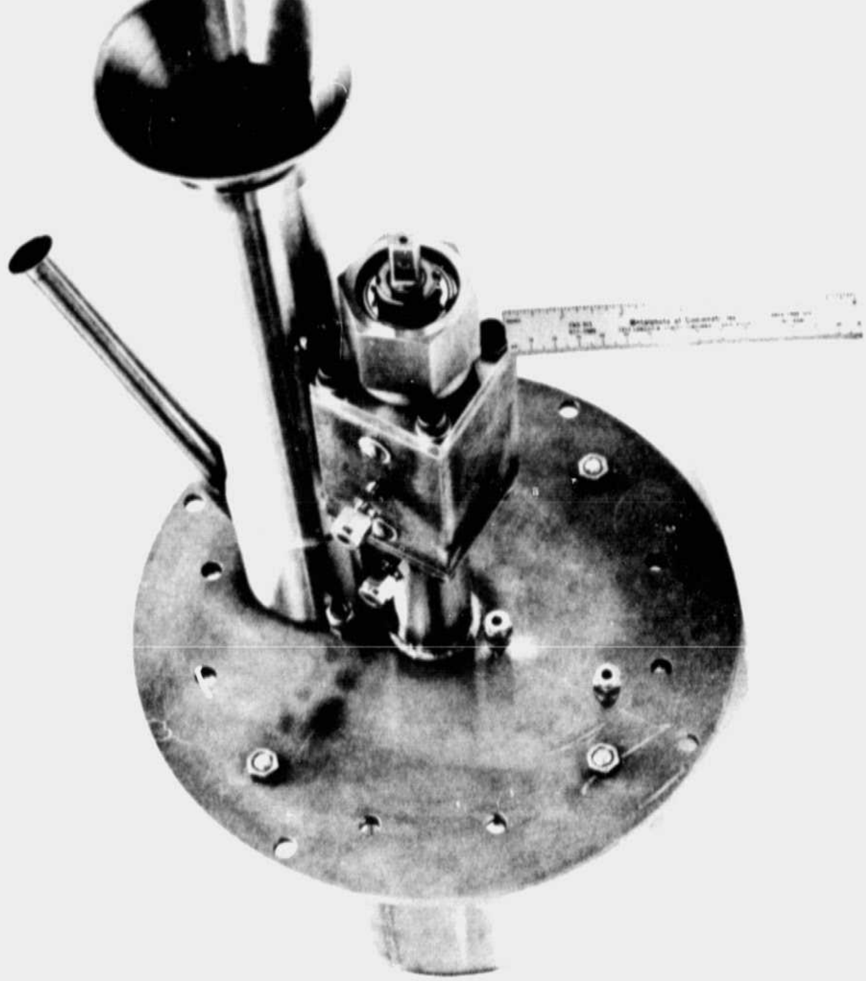

Figure 3 ROTATING-PADDLE INCINERATOR - INLET END

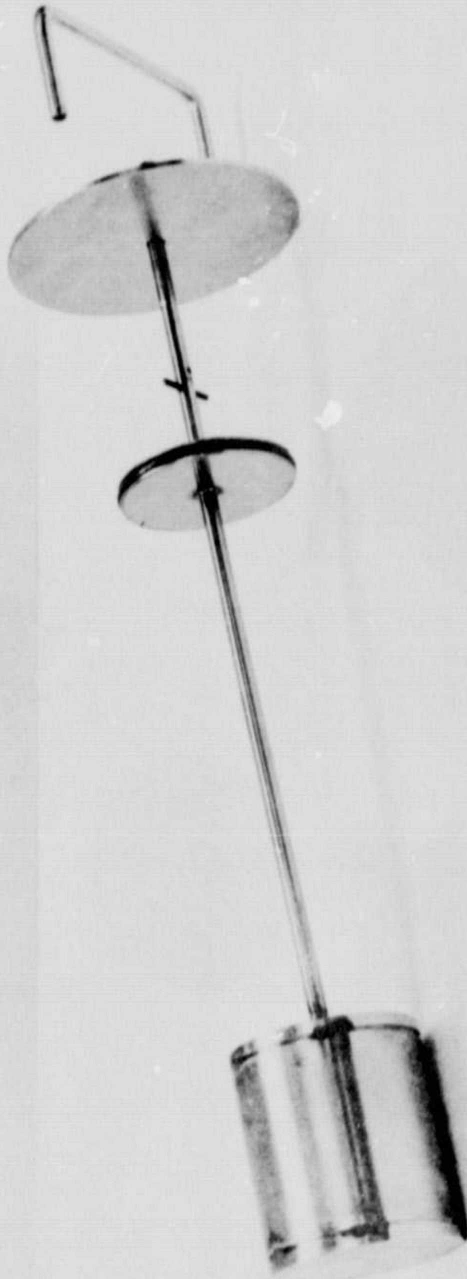

Figure 4 TRANSPORT TUBE PLUG/SEAL

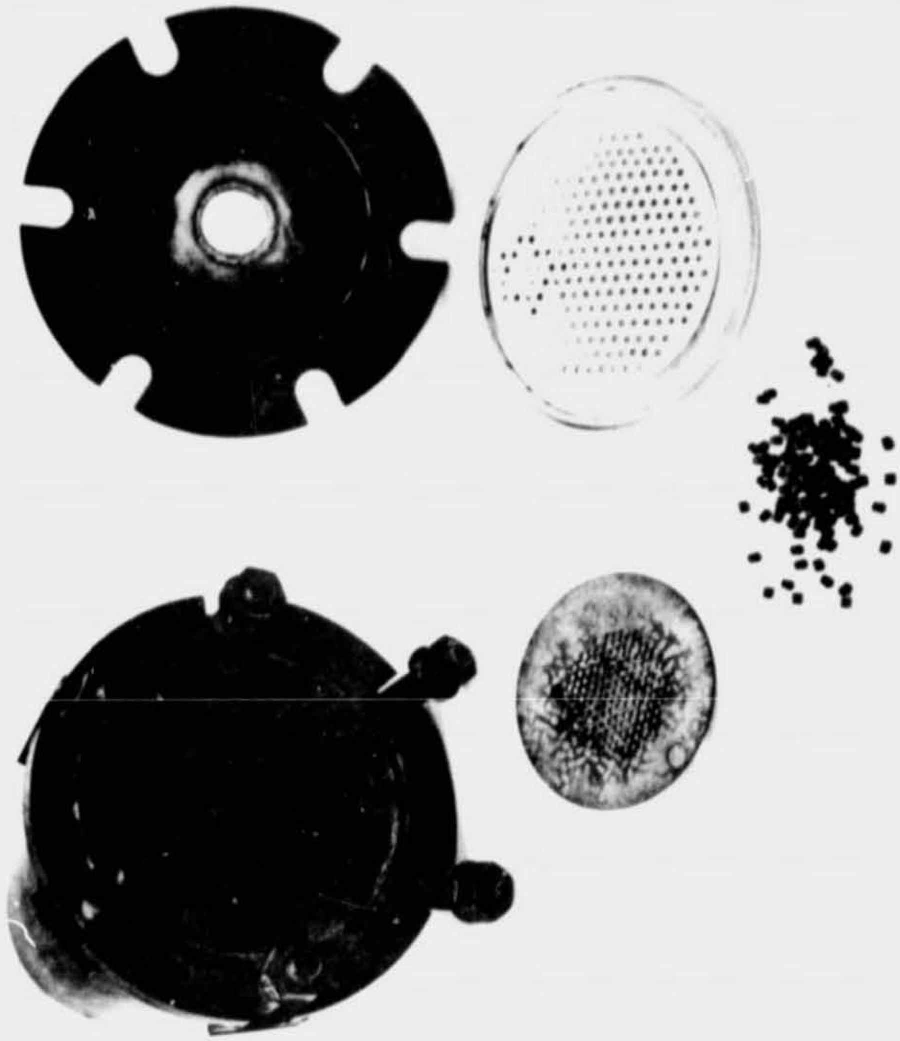

Figure 5 CATALYTIC AFTERBURNER - DISASSEMBLED

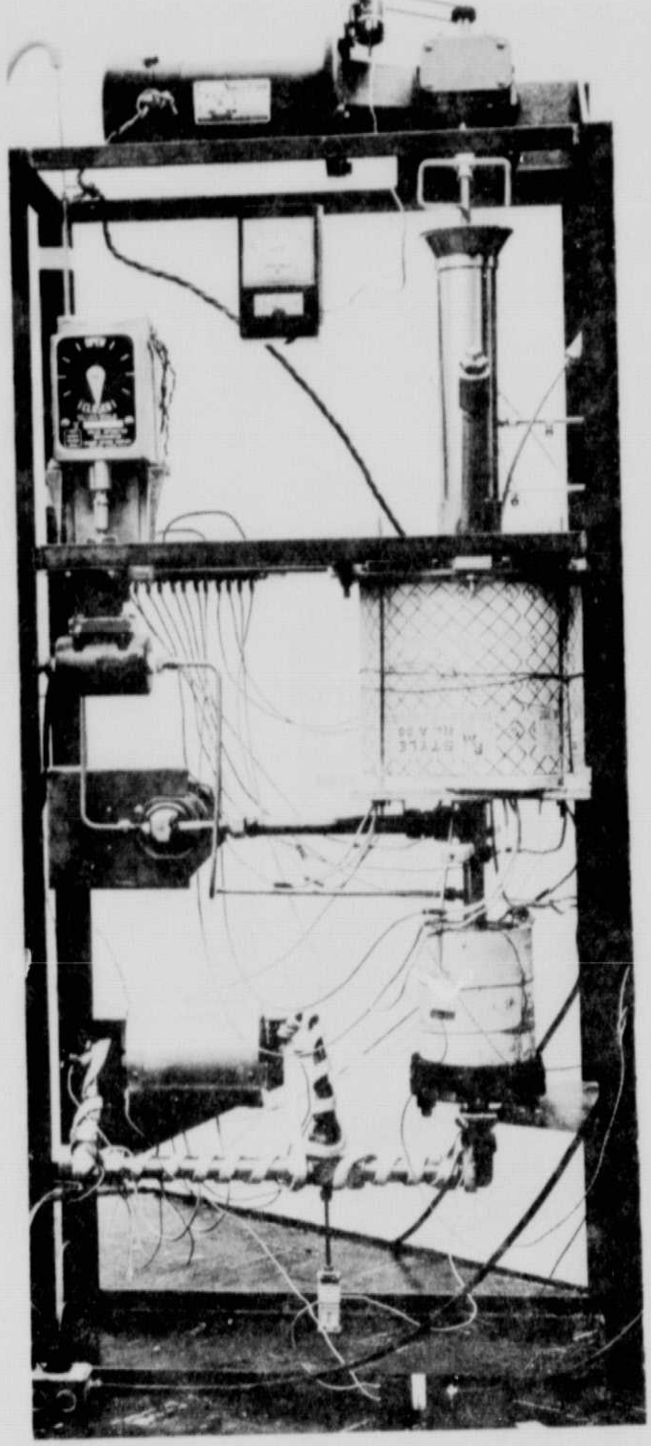

Figure 6 ASSEMBLED BASELINE SUBSYSTEM - INSULATION REMOVED

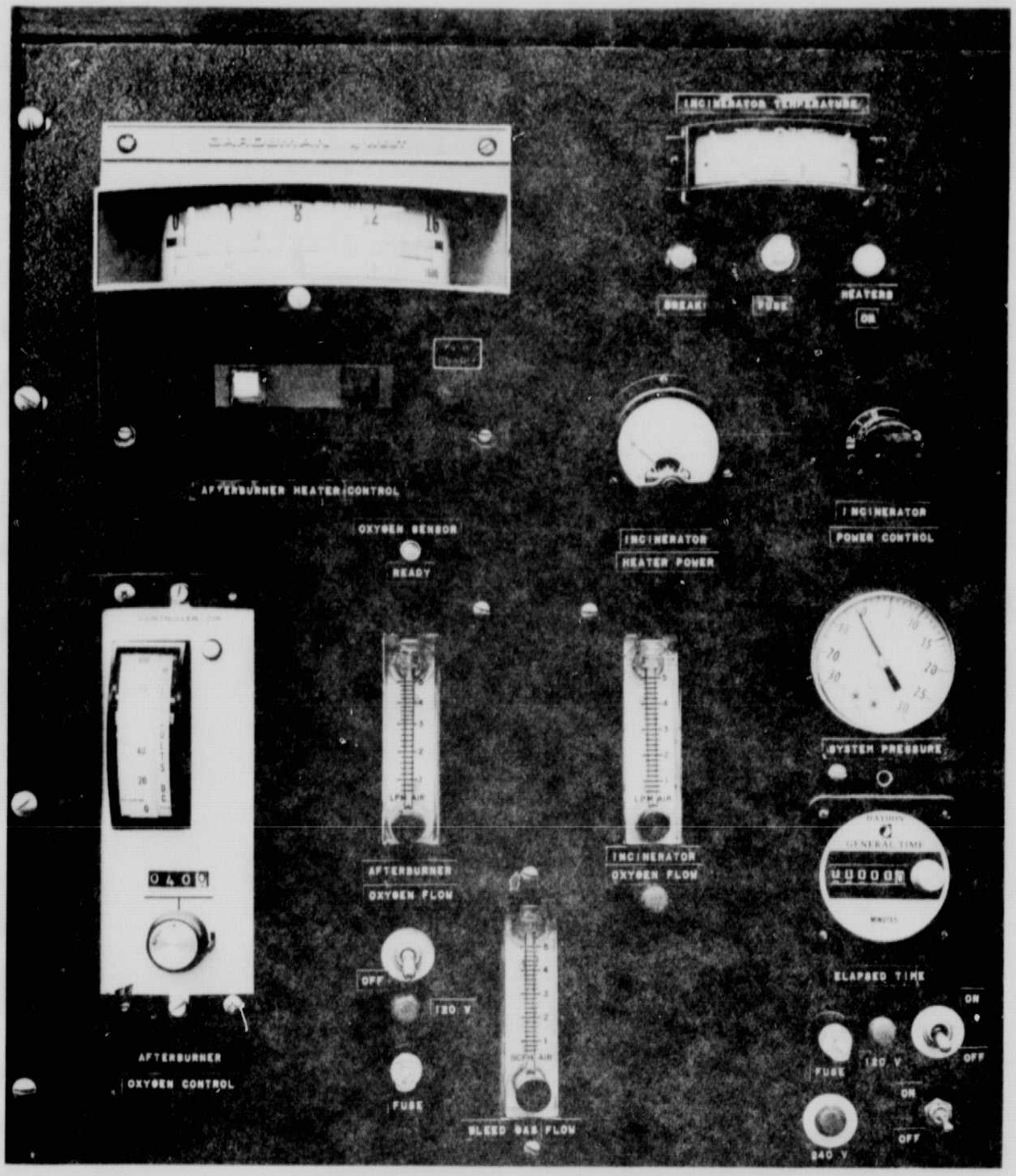


Figure 7 MAIN CONTROL PANEL

In order to monitor temperatures throughout the subsystem, thermocouples were placed at eight different locations and their output recorded on a strip chart recorder. Thermocouple locations were as follows:

Incinerator inlet end plate (adjacent to shell)

Incinerator inlet end plate (adjacent to labyrinth seal)

Incinerator inlet end plate (adjacent to waste transport tube)

Incinerator exhaust end plate (adjacent to shell)

Catalytic afterburner catalyst

Catalytic afterburner exhaust line

Oxygen sensor inlet line

Exhaust line to condenser

## 2.2 Laboratory Test Procedure

For a description of the basic operation of the subsystem, the reader is referred to Appendix A. The operational procedure described in Appendix A was altered a number of times during the test series, and these alterations are noted as they occurred in the description of the individual tests in Section 2.3.

At the end of each test, the product ash, condensate, and gas were analyzed. The weight and color of the collected ash were determined. The collected condensate was subjected to both physical and chemical analysis. Physical analysis included the determination of weight, color, and total solids concentration. Chemical analysis included the determination of electrical conductivity, pH, concentrations of organic and inorganic carbon, and concentrations of ammonium, chloride, and sulfate ions.

Gas analysis included the determination of total collected gas volume and identification of constituent gases. Gas samples were injected into a gas chromatograph fitted with molecular sieve and poropak columns to determine

the volume percentages of carbon dioxide, hydrogen, oxygen, nitrogen, carbon monoxide, methane, acetylene, and ethane. Gas detector tubes were employed for determining the concentrations of hydrogen sulfide, sulfur dioxide, ammonia, and nitrogen dioxide.

Sterility tests of the end products were in general not performed since normal operation of the subsystem completely satisfied the requirements described in Reference 2 for total end product sterility. Sterility tests (a description of the procedure can be found in Reference 2) of the end products for Test Number 1 were performed, and all end products were found to be sterile.

## 2.3 Individual Tests

### Check-Out Test, 31 May 1974

A check-out test was conducted prior to the two-week test series to establish test procedure as fully as possible and to identify potential problem areas in the operation of the subsystem. While ash, condensate, and gas collection were carried out, no detailed analysis of the end products for this test was planned or performed.

The check-out test was run with the subsystem oriented vertically (with the rotational axis of the incinerator and the waste transport tube oriented vertically). The rotational speed of the paddle blade assembly was maintained at 300 rpm. The carbon dioxide gas flow rate was maintained at .85 lpm through the bearing housing and the labyrinth seal between the paddle blade assembly drive shaft and the inlet end plate of the incinerator. The catalytic afterburner heaters were controlled to maintain a catalyst bed temperature of 427°C, while the gas line tape heaters were adjusted (through the use of standard variacs) to maintain gas line temperatures between 371°C and 427°C. The incinerator was loaded in the prescribed fashion (see Appendix A) with the following waste materials:

| | |
|---|---|
| Human Feces | 900 gm |
| Urine Distillate Residue* | 900 gm |
| Rinse Water | 320 gm |
| Toilet Tissue | 20 gm |
| Disposable Liner | 11 gm |
| Total | 2151 gm |

The disposable liner used for this particular test was fabricated in the laboratory from "48# Dry Wax" manufactured by Central States Paper and Bag Co., St. Louis, Missouri. This liner material was tested and recommended as satisfactory for use under Task I (see Reference 3).

Loading of the wastes into the incinerator was performed with a blower connected to the catalytic afterburner exhaust line just upstream of the laboratory condenser arrangement. The blower produced a pneumatic transport air flow rate of approximately 700 lpm. This air flow rate was marginally sufficient for satisfactory pneumatic transport of waste materials and also lowered the catalyst bed temperature to 107°C. At the end of loading, the disposable liner was released to the incinerator; this caused jamming of the paddle blade assembly against the shear bar and stoppage of rotation. Rotation was quickly restored after manually rotating the paddle blade assembly slightly in the reverse direction. The waste transport tube plug/seal was then brought into position, and the blower was shut off and removed.

After the catalyst bed temperature had fully recovered, the incinerator heater power was set at 1500 watts (the maximum possible) to initiate the incineration cycle (time zero). It soon became apparent that the proportional controller in the oxygen supply line to the catalytic afterburner was not functioning properly (it would open the oxygen supply line valve as required,

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* Approximately 50% solids, by weight.

but it would not operate at all in the reverse direction). Because of this, the valve operated by the proportional controller was left open, and control of the oxygen flow rate to the catalytic afterburner was achieved by manually adjusting the valve at the rotometer in this supply line. Adjustments were made as required to maintain oxygen sensor readings for the afterburner exhaust gas equivalent to 5 to 6% oxygen by volume in this gas.

Gases and vapors produced during the process of boil-off led to a reduction in the catalyst bed temperature to 277°C. This temperature reduction was followed by an increase in catalyst bed temperature to 749°C early in the process of pyrolysis, corresponding to excessive demand for oxygen within the afterburner (greater than 5 lpm, the maximum possible flow rate through the rotameter). Simultaneously, the rotational speed of the paddle blade assembly began to decrease, eventually stopping altogether about half an hour after the end of boil-off (this stoppage resulted in twisting of the flexible drive shaft).

The incinerator heater power was reduced to 600 watts at an incinerator temperature of 216°C and shut off altogether at a temperature of 371°C in an effort to control the catalyst bed temperature while supplying the required amount of oxygen. After failing to do this, it was decided to abandon further oxidation within the afterburner (238 liters of oxygen had been supplied) and to heat the incinerator to 538°C at a heater power setting of 900 watts. Once this was accomplished, the incinerator heaters were shut off, and oxygen was supplied to the incinerator as required to maintain an excess of oxygen in the subsystem exhaust gas of 5 to 6% by volume. A total of 87 liters of oxygen were supplied to the incinerator in 45 minutes, producing an increase in incinerator temperature of about 40°C. The incinerator oxidation process ended 245 minutes after time zero.

After cool down of the subsystem, the paddle blade assembly was manually broken free to restore rotation. The resulting gray ash, primarily in the form of large chunks, was removed by reverse flushing of air through the incinerator with a vacuum cleaner and by using probes to break up and remove the large chunks of ash. Since no damage to the incinerator proper was observed, the flexible drive shaft was replaced, and the subsystem was reheated and purged with oxygen to oxidize any remaining unoxidized wastes.

As a result of the check-out test, a number of alterations in the procedure for operating the subsystem were adopted for the subsequent test series. First, it was decided to abaondon operation of a transport air blower and to load the waste materials (feces and urine distillate residue) in the form of a slurry. The air flow rate realized with the blower was simply not sufficient for satisfactory pneumatic transport of the wastes, and it produced cooling of the catalyst bed which could clearly lead to the production of unsterile end products. Much higher (satisfactory) air flow rates could have been realized and cooling of the catalyst bed could have been avoided by connecting the blower to the incinerator exhaust line upstream of the catalytic afterburner. However, this modification in the design of the subsystem would have severely reduced the time available to perform the test series and was therefore not made.

Second, use of the proportional controller in the oxygen supply line to the catalytic afterburner was abandoned for the test series in favor of the previously described procedure of manual control of the oxygen flow rate. This decision was made after it was established that the proportional controller could not be made to operate properly in the laboratory.

For all tests in the test series, the rotational speed of the paddle blade assembly was maintained at 300 rpm; the carbon dioxide gas flow rate was maintained at .85 lpm through the bearing housing and the labyrinth

seal between the paddle blade assembly drive shaft and the inlet end plate of the incinerator; the catalytic afterburner heaters were controlled to maintain a catalyst bed temperature of 371°C; and the gas line tape heaters were adjusted to maintain gas line temperatures between 316°C and 427°C.

Test Number 1, 4 June 1974, Vertical Orientation

The incinerator was loaded with the following waste materials:

| | |
|---|---|
| Human Feces | 835 gm |
| Urine Distillate Residue* | 900 gm |
| Rinse Water | 320 gm |
| Toilet Tissue | 29 gm |
| Disposable Liner | 7 gm |
| Total | 2082 gm |

The disposable liner used for this test was fabricated from a lighter material than that used for the check-out test, "20# White #84600 M.G. Kraft - 4# Waxsorb" manufactured by Thilmany Pulp and Paper Co., Kaukauna, Wisconsin. This liner material was also tested and recommended as satisfactory for use under Task I (see Reference 3).

The disposable liner was pushed with some difficulty into the incinerator after loading of the wastes, but with no apparent effect on the rotation of the paddle blade assembly. After positioning the waste transport tube plug/seal, the incinerator heater power was set at 600 watts (time zero) in an attempt to avoid producing the large demand for oxygen within the afterburner encountered during the check-out test. The catalyst bed temperature decreased to 332°C during boil-off and then increased sharply during the early part of pyrolysis. At incinerator temperatures of 191°C and 210°C, the incinerator heater power was reduced to 450 watts and 300 watts, respectively,in a successful attempt at controlling the demand for oxygen within the afterburner

* Approximately 50% solids, by weight.

as well as the catalyst bed temperature. The catalyst bed temperature increased to 732°C at an incinerator temperature of 260°C and remained between 704°C and 760°C until the incinerator oxidation process, during which it eventually decreased to 538°C.

In a fashion similar to the check-out test, the rotational speed of the paddle blade assembly began to decrease at an incinerator temperature of 121°C, eventually stopping altogether at an incinerator temperature of 268°C (this stoppage resulted in twisting of the flexible drive shaft). After approximately 10 minutes (with all other operations proceeding normally), full rotational speed was restored by manually rotating the paddle blade assembly to break it free. Rotation continued unaffected throughout the remainder of the test.

Power to the incinerator heaters was increased without difficulty to 450 watts, 600 watts, and 750 watts at incinerator temperatures of 332°C, 366°C, and 399°C, respectively. Once an incinerator temperature of 538°C was attained, the incinerator heaters were shut off, and the incinerator oxidation process was carried out as for the check-out test. This process lasted 95 minutes, producing an incinerator temperature increase of 56°C. It ended 440 minutes after time zero.

After cool down of the subsystem, ash was removed from the incinerator in a similar fashion to that used after the check-out test. The collected ash was gray and consisted of 92 gm of chunks and 58 gm of powder.

The flexible drive shaft was again replaced, and a leak in the gas collection envelope was repaired in preparation for the next test. (This leak had been detected and repaired as best as possible during the latter part of pyrolysis.)

Test Number 2, 6 June 1974, Horizontal Orientation

Loading of the wastes into the incinerator for this and subsequent tests (all of which were performed with the subsystem horizontal) was performed with the support frame slightly inclined with respect to the horizontal in order to make favorable use of gravity. In addition, because of the difficulty encountered in pushing the disposable liner into the incinerator during Test Number 1, the disposable liner was simply removed after loading of the wastes into the incinerator. After positioning the waste transport tube plug/seal, the subsystem was then placed in a completely horizontal orientation in preparation for initiation of the incineration cycle.

The waste load for this test consisted of the following materials:

| | |
|---|---|
| Human Feces | 900 gm |
| Urine Distillate Residue* | 900 gm |
| Rinse Water | 350 gm |
| Toilet Tissue | 20 gm |
| Total | 2170 gm |

At time zero the incinerator heater power was set at 500 watts. The catalyst bed temperature decreased to 327°C during boil-off and then increased in much the same fashion as for Test Number 1. At the end of boil-off, at an incinerator temperature of 107°C, the incinerator heater power was reduced to 250 watts. As in Test Number 1, the rotational speed of the paddle blade assembly began to decrease at an incinerator temperature of 121°C, eventually decreasing to about 100 rpm before returning to normal at an incinerator temperature of 243°C. (Additional external air cooling applied to the motor housing during the course of this test apparently prevented total loss of rotation speed.)

* Approximately 50% solids, by weight.

Power to the incinerator heaters was increased without difficulty to 400 watts, 500 watts, 600 watts, and 750 watts at incinerator temperatures of 249°C, 271°C, 293°C, and 391°C, respectively. However, at an incinerator temperature of 410°C, the test had to be stopped when it was detected that the incinerator exhaust tube connection to the catalytic afterburner had melted and been destroyed just downstream of the afterburner oxygen supply line fitting. The test was stopped 350 minutes after time zero with the temperature of the catalyst bed at 732°C. (The temperature at the inlet end of the afterburner was obviously very near the melting point temperature for Hastelloy X. This region of the afterburner was found to be bright orange upon removal of the insulation at this location.)

After cool down of the subsystem, ash was removed from the incinerator as before. The collected ash was gray and consisted of 186 gm of chunks and 151 gm of powder.

The catalytic afterburner was removed from the subsystem and rebuilt with a new inlet end plate, inlet tube, oxygen supply fitting, inlet catalyst retaining screen, and catalyst. In addition, the thermocouple sensing the catalyst bed temperature for the recorder was repositioned 2.5 cm from the afterburner inlet end plate in order to be more sensitive to temperature variations in this region. The afterburner was then reinstalled in the subsystem with considerably less and looser insulation around it than before.

The new oxygen supply fitting made it possible to supply oxygen axially in the direction of, and at the center of, the gas flow exhausting from the incinerator into the catalytic afterburner. This new arrangement was designed primarily to reduce the possibility of regions of gas having high oxygen concentrations coming into contact with Hastelloy X. (The original fitting simply supplied oxygen at the wall of the tube connecting the incinerator and afterburner in a radial or cross-flow direction.)

Test Number 3, 11 June 1974, Horizontal Orientation

The waste load for this and the remaining two tests was reduced to approximately half that used previously in an effort to maintain continuous, full paddle blade assembly rotation and thereby prevent the formation of chunks of wastes within the incinerator during pyrolysis. The waste load for Tests 3, 4, and 5 consisted of the following materials:

| | |
|---|---|
| Human Feces | 450 gm |
| Urine Distillate Residue* | 450 gm |
| Rinse Water | 160 gm |
| Toilet Tissue | 10 gm |
| Total | 1070 gm |

At time zero the incinerator heater power was set at 500 watts. The catalyst bed temperature, measured 2.5 cm from the afterburner inlet end plate, decreased to 210°C during boil-off. (The temperature at the center of the catalyst bed, which was monitored with a separate thermocouple as before to control afterburner heater power, remained above 320°C during this and the remaining two tests.) At the end of boil-off, at an incinerator temperature of 110°C, the incinerator heater power was reduced to 250 watts. It was later increased to 500 watts, 750 watts, and 1000 watts at incinerator temperatures of 260°C, 316°C, and 454°C,respectively. During the course of pyrolysis, insulation at the catalytic afterburner inlet was removed and replaced as required to control the temperature in this region. A peak catalyst bed temperature of 838°C was measured at the new thermocouple location, but no apparent damage occurred as a result of this temperature. In addition, paddle blade assembly rotation was maintained without difficulty during the course of this test, although definite chunk break-up could be heard at various times during pyrolysis.

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* Approximately 50% solids, by weight.

The incinerator oxidation process lasted 53 minutes, producing an incinerator temperature increase of 33°C. It ended 410 minutes after time zero.

After cool down of the subsystem, ash was removed by reverse flushing of air through the incinerator with a vacuum cleaner. The collected ash was gray and consisted of 44 gm of powder. (No chunks were found within the incinerator.)

Test Number 4, 12 June 1974, Horizontal Orientation

The procedure for this test was basically identical to that of the previous test. (The incinerator heater power was reduced to 250 watts at a slightly higher incinerator temperature of 127°C.)

The catalyst bed temperature, measured 2.5 cm from the afterburner inlet end plate, decreased to 202°C during boil-off. During the course of pyrolysis, a peak catalyst bed temperature of 638°C was reached at the same location due to somewhat better adjustment of the insulation around the afterburner inlet than that performed during the previous test. The incinerator oxidation process lasted 57 minutes, producing an incinerator temperature increase of 19°C. It ended 397 minutes after time zero.

During the incinerator oxidation process, pressure within the subsystem increased to about 1.3 atmospheres and was restored to normal by flaming the catalytic afterburner inlet. After cool down of the subsystem, the afterburner was disconnected from the incinerator for inspection. Fine ash was found to be blocking the holes in the catalyst retaining screen at the inlet end of the afterburner. The holes were cleaned out and the subsystem reassembled. ( No damage to metal parts in this region was observed.)

Ash was removed as after Test Number 3, although in this case a much higher air flow rate through the incinerator was attained because the afterburner was disconnected from the incinerator at the time of ash removal. The collected ash was gray and consisted of 61 gm of powder.

Test Number 5, 13 June 1974, Horizontal Orientation

The procedure for this test was again basically identical to that of Test Number 3 except that the reduction in incinerator heater power to 250 watts was omitted. The catalyst bed temperature, measured 2.5 cm from the afterburner inlet end plate, decreased to 218°C during boil-off and reached a peak of 713°C during pyrolysis. A slight increase (less than .1 atm) in subsystem pressure occurred at an incinerator temperature of about 400°C. Subsystem pressure returned to normal about half way through the incinerator oxidation process (flaming of the catalytic afterburner inlet failed to relieve the excess pressure in this case). Paddle blade assembly rotation was again very smooth throughout the test.

The incinerator oxidation process lasted 51 minutes, producing an incinerator temperature increase of 11°C. It ended 318 minutes after time zero.

Ash was removed as after Test Number 3. The collected ash was gray and consisted of 41 gm of powder.

## Section 3

## TEST DATA

### 3.1 Final Condition of the Subsystem

The subsystem was disassembled immediately after the test series for visual inspection and determination of the quantity of residual ash (ash not removed by the normal evacuation procedure) remaining within the incinerator. The following residual amounts of ash were collected:

| | |
|---|---|
| Paddle Blade Assembly | 25 gm |
| Inlet End Plate | 25 gm |
| Shell and Exhaust End Plate | 100 gm |
| Total | 150 gm |

This residual ash and the condition of the interior of the incinerator can be seen in Figures 8 through 10. It should be noted that the condition of all pieces of hardware appeared to be excellent throughout the subsystem. In particular, the bearing housing was completely clean, indicating effective operation of the labyrinth seal between the incinerator inlet end plate and the paddle blade assembly drive shaft; there was no evidence of permanent bending or torsion of the paddle blade assembly; the catalytic afterburner showed no signs of metal erosion in the vicinity of the new oxygen supply fitting; and all gas lines were for the most part free of any tar or ash. The only exception to this was the tube connecting the incinerator to the catalytic afterburner, which contained a small amount of fine ash. The holes in the catalyst retaining screen at the inlet end of the after-burner were also partially blocked with ash, and some fine black ash was found within the catalyst bed itself.

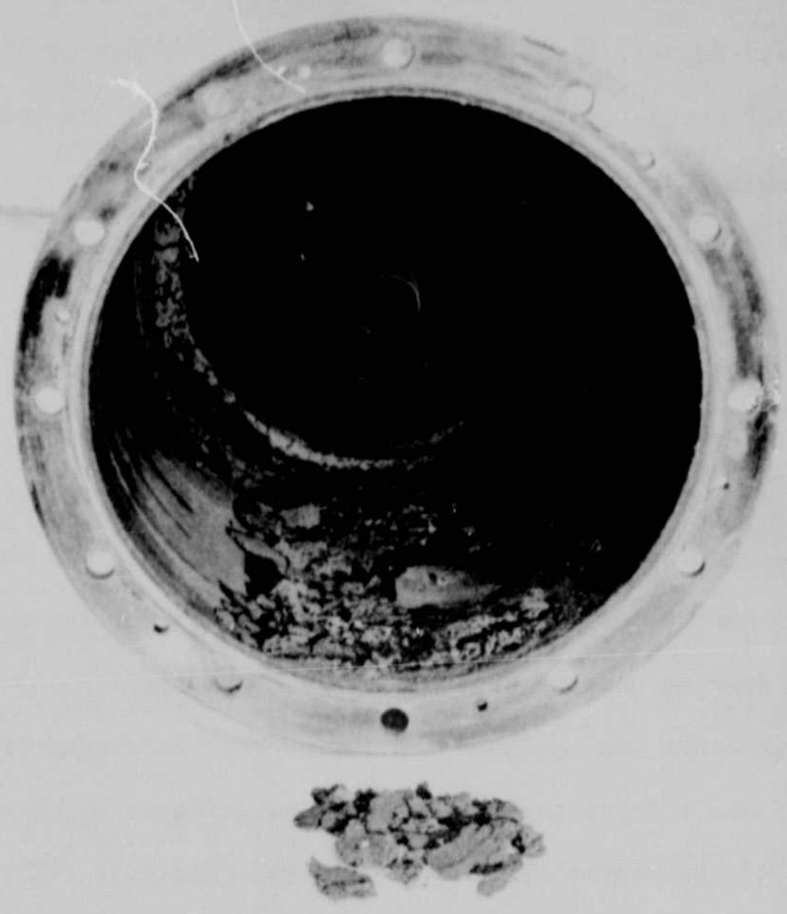


Figure 8 RESIDUAL ASH WITHIN INCINERATOR SHELL AND ON EXHAUST END PLATE AT END OF TEST SERIES

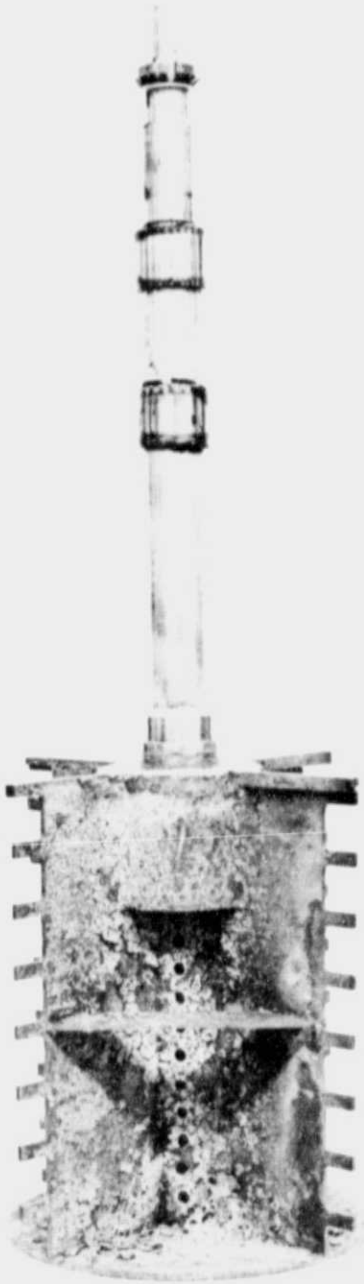


Figure 9 RESIDUAL ASH ON PADDLE BLADE ASSEMBLY AT END OF TEST SERIES

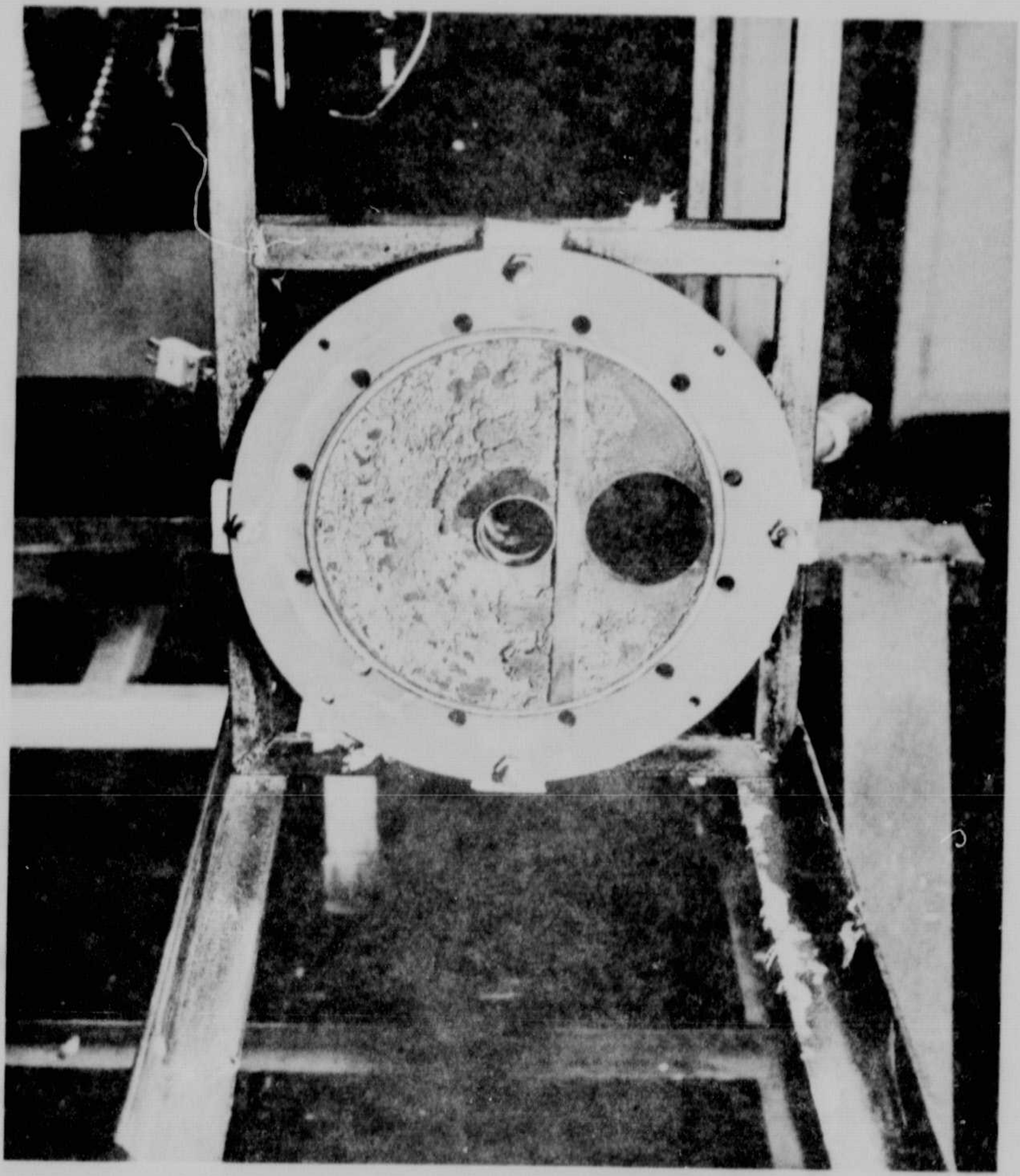


Figure 10 RESIDUAL ASH ON INCINERATOR INLET END PLATE AT END OF TEST SERIES

## 3.2 Oxygen Consumption Through Pyrolysis

Figures 11 and 12 summarize for each of the five tests the history of oxygen consumption within the catalytic afterburner through pyrolysis as a function of incinerator temperature. The sharp changes in the curves for Test Numbers 2 and 3 correspond to audible break-up of chunks of wastes within the incinerator during those tests. Heating rates are also shown on the figures for completeness. Of particular interest is the initial lag in oxygen consumption for Test Number 5 over that for Test Number 4 apparently caused by the higher rate of heating employed during part of the last test.

A slightly larger waste load was used for Test Number 2 than for Test Number 1; hence, the somewhat higher oxygen consumption for this test (up to the point of shut-down) in comparison with Test Number 1. Test Numbers 3 through 5 were run with identical waste loads which were approximately half those used for the first two tests. The somewhat higher oxygen consumption and also the chunk break-up observed during Test Number 3 can most likely be attributed to processing of residual chunks of wastes remaining within the incinerator after the first two tests.

## 3.3 Gas and Condensate Analyses, Mass Balances

Tables 1 through 4 present the major portion of test data gathered during the five tests. Table 1 summarizes the input quantities for each test, Table 2 the primary output quantities, Table 3 the trace output gases, and Table 4 the condensate. All of these tables should be interpreted with the knowledge that gas collection for Test Number 1 was incomplete due to a leak in the gas collection envelope, and that Test Number 2 was aborted toward the end of pyrolysis due to burn out of the Hastelloy X tubing connecting the incinerator and catalytic afterburner (just downstream of the afterburner oxygen supply fitting). The large deficit between total input and total output for

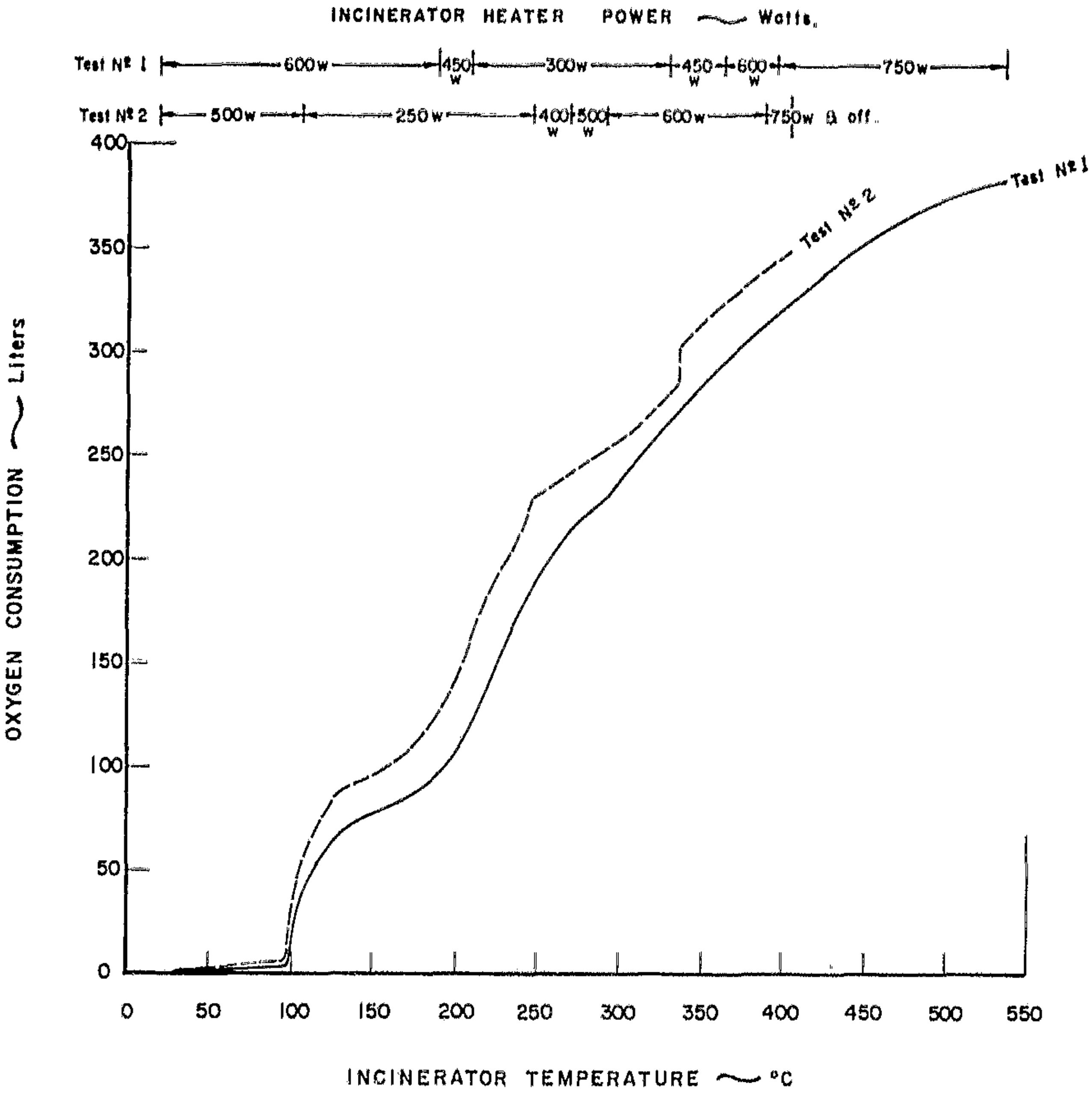



Figure 11 CATALYTIC AFTERBURNER OXYGEN CONSUMPTION THROUGH PYROLYSIS VERSUS INCINERATOR TEMPERATURE: TEST NUMBERS 1 AND 2

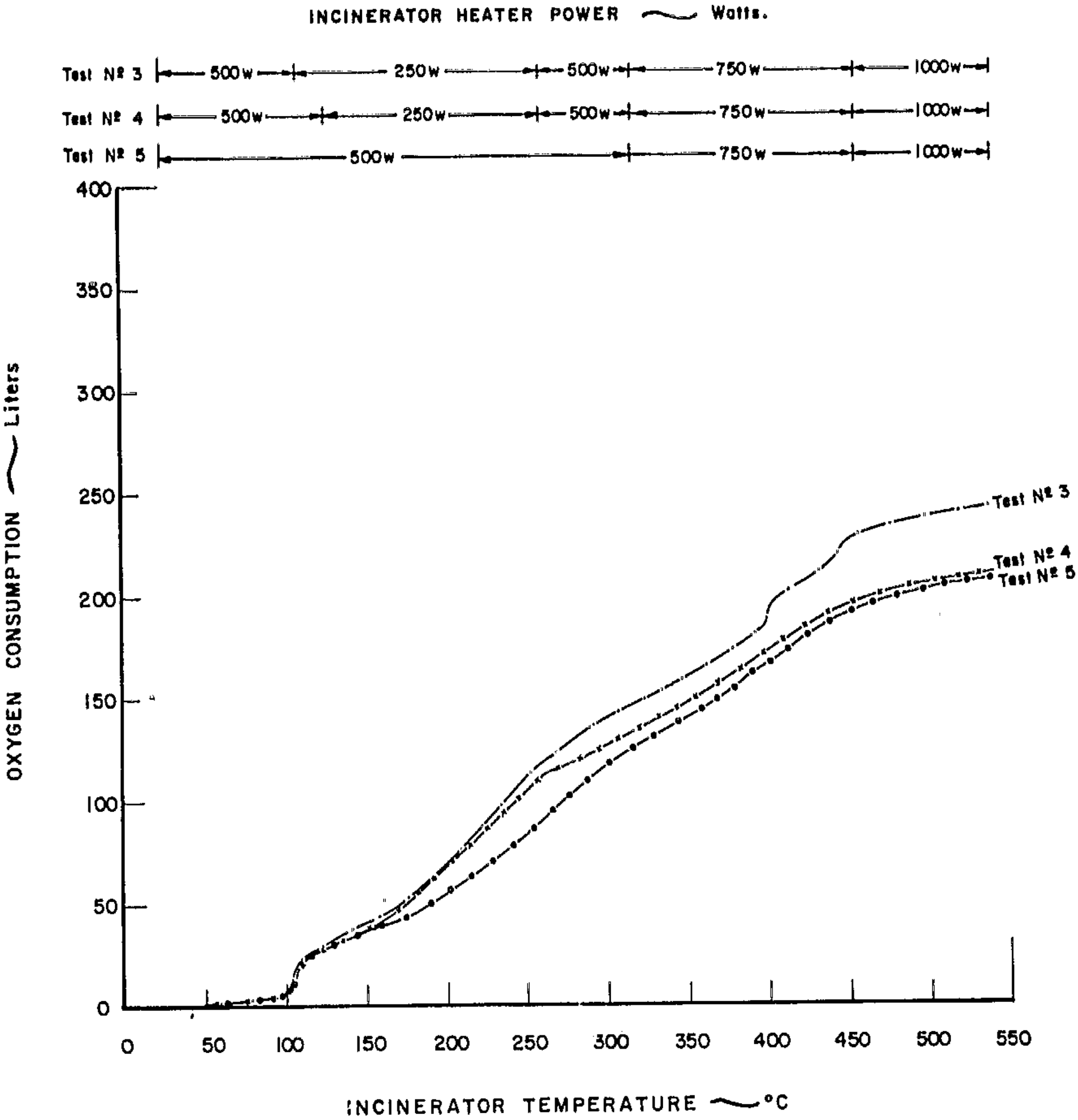



Figure 12 CATALYTIC AFTERBURNER OXYGEN CONSUMPTION THROUGH PYROLYSIS VERSUS INCINERATOR TEMPERATURE: TEST NUMBERS 3, 4, AND 5

Table 1

INPUT QUANTITIES

| Test Number | 1 | 2* | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Feces (gm) | 835 | 900 | 450 | 450 | 450 |
| UDR** (gm) | 900 | 900 | 450 | 450 | 450 |
| Toilet Paper (gm) | 20 | 20 | 10 | 10 | 10 |
| Disposable Liner (gm) | 7 | -- | -- | -- | -- |
| Water (gm) | 320 | 350 | 160 | 160 | 160 |
| Total Waste Load (gm) | 2082 | 2170 | 1070 | 1070 | 1070 |
| Incinerator $O_2$ (liter) | 144 | -- | 109 | 87 | 87 |
| (gm) | 190 | | 144 | 115 | 115 |
| Afterburner $O_2$ (liter) | 394 | 348 | 256 | 220 | 216 |
| (gm) | 522 | 461 | 340 | 291 | 286 |
| Total $O_2$ (liter) | 538 | 348 | 365 | 307 | 303 |
| (gm) | 712 | 461 | 484 | 406 | 401 |
| $CO_2$ (liter) | 313 | 297 | 315 | 301 | 238 |
| (gm) | 573 | 544 | 575 | 550 | 434 |
| Total Input (gm) | 3367 | 3175 | 2129 | 2026 | 1905 |

* Test aborted during pyrolysis at an incinerator temperature of 410°C.

** Urine Distillate Residue (50% solids, by weight).

Table 2

PRIMARY OUTPUT QUANTITIES

| Test Number | 1* | 2** | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $CO_2$ (%) | 64.5 | 57.2 | 75.0 | 68.0 | 65.5 |
| (liter) | 278 | 335 | 404 | 389 | 330 |
| (gm) | 508 | 613 | 738 | 711 | 604 |
| $H_2$ (%) | 2.9 | 2.0 | 0 | 0 | 0 |
| (liter) | 13 | 12 | 0 | 0 | 0 |
| (gm) | 1 | 1 | 0 | 0 | 0 |
| $O_2$ (%) | 13.7 | 21.5 | 10.4 | 16.1 | 14.8 |
| (liter) | 59 | 126 | 56 | 92 | 75 |
| (gm) | 78 | 167 | 74 | 122 | 99 |
| $N_2$ (%) | 17.7 | 17.3 | 14.4 | 15.7 | 19.5 |
| (liter) | 76 | 101 | 77 | 90 | 98 |
| (gm) | 89 | 118 | 90 | 104 | 114 |
| CO (%) | 1.2 | 2.0 | 0.2 | 0.2 | 0.2 |
| (liter) | 5 | 12 | 1 | 1 | 1 |
| (gm) | 6 | 13 | 1 | 1 | 1 |
| Total Gas (%) | 100 | 100 | 100 | 100 | 100 |
| (liter) | 431 | 586 | 538 | 572 | 504 |
| (gm) | 682 | 912 | 903 | 938 | 818 |
| Condensate (gm) | 1670 | 1733 | 917 | 847 | 856 |
| Collected Ash*** (gm) | 150 | 337 | 44 | 61 | 41 |
| Total Output (gm) | 2502 | 2982 | 1864 | 1846 | 1715 |
| Total Deficit (gm) (Input-Output) | 865 | 193 | 265 | 180 | 190 |

* Gas collection incomplete due to leakage in gas collection envelope.

** Test aborted during pyrolysis at an incinerator temperature of 410°C.

*** Residual ash (150 gm) remaining in incinerator after test series not included.

Table 3

TRACE OUTPUT GASES

| Test Number | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $NH_3$ (ppm) | <5 | <5 | <5 | <5 | <5 |
| $SO_2$ (ppm) | <1 | <1 | 20 | 1 | 1 |
| $H_2S$ (%) | >.64 | .02 | <.005 | <.005 | <.005 |
| $NO_2$ (ppm) | 25 | 50 | 300 | 100 | 100 |

Table 4

CONDENSATE ANALYSIS

| Test Number | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Liquid Color | yellow | yellow | light green | yellow | yellow green |
| Sediment Color* | light brown | dark brown | none | light brown | light brown |
| pH | 8.0 | 6.6 | 1.3 | 6.8 | 3.2 |
| Electrical Conductivity (mmhos) | 15 | 10.2 | 11.8 | 7.2 | 11.6 |
| $NH_4^+$ Concentration (ppm) | 4900 | 2500 | 950 | 3200 | 2800 |
| $CL^-$ Concentration (ppm) | 6120 | 3195 | 1534 | 123 | 4580 |
| $SO_4^=$ Concentration (ppm) | 738 | 1125 | 850 | 863 | 1375 |
| Inorganic Carbon (ppm) | 286 | 451 | 123 | 1560 | 180 |
| Organic Carbon (ppm) | 836 | 723 | 29 | 1690 | 4770 |
| Total Carbon (ppm) | 1122 | 1174 | 152 | 3250 | 4950 |
| Total Solids (%) | 1.410 | 0.630 | 0.414 | 0.442 | 0.987 |

* Condensate for all tests contained small amounts of black soot.

Test Number 1 is therefore entirely reasonable, and it is also reasonable to expect the results of both Tests 1 and 2 to have been affected to some degree by the erosion undergone by the Haselloy X tubing. Both of these tests yielded, for example, uncharacteristically high concentrations of hydrogen, carbon monoxide, and hydrogen sulfide in comparison with the remaining three tests.

No evidence of methane, acetylene, or ethane was found after any of the tests.

The total deficits noted in Table 2, for Tests 3 through 5 in particular, remain unexplained. Leaks in the subsystem certainly could have led to such deficits although the subsystem was thoroughly leak-checked just prior to the test series. These deficits are also not substantially altered by the addition of the 150 gm of residual ash found within the incinerator after the test series.

3.4 Power and Energy Consumption

Approximate power and energy consumption during the test series are summarized in Tables 5 and 6, respectively. These tables do not include warm-up operations which lasted about one hour prior to each test and involved the catalytic afterburner, gas line tape heaters, oxygen sensor, and miscellaneous controls. Power and energy consumption during warm-up were therefore 800 watts and .800 kwhr, respectively.

Comparison between Test Number 1 and Test Numbers 3 through 5 shows that for a reduction of approximately 50% in the waste load, energy consumption was reduced by 10% for Test Number 3, 14% for Test Number 4, and 24% for Test Number 5 (a higher rate of incinerator heating was employed during the first half of Test Number 5 in comparison with Test Numbers 3 and 4). These results indicate that the subsystem operates more efficiently in terms of energy consumption when processing the waste load for which it was designed.

Table 5

POWER CONSUMPTION

| Elapsed Test Time (minutes) | Incinerator Temperature ($^oC$) | Incinerator Heater Power (watts) | Afterburner Heater Power (watts) | Tape Heater Power (watts) | Motor Power Paddle Blade Rotation (watts) | $O_2$ Sensor, Miscellaneous Power (watts) |
|---|---|---|---|---|---|---|
| | | | (Test Number 1) | | | |
| 0 | Ambient | 600 | 500 | 200 | 300 | 100 |
| 138 | 121 | | off | | | |
| 159 | 191 | 450 | - | | | |
| 163 | 210 | 300 | - | | | |
| 251 | 332 | 450 | - | | | |
| 272 | 366 | 600 | - | | | |
| 290 | 399 | 750 | - | | | |
| 345 | 538 | off | - | | | |
| 440 | | | END OF TEST | | | |
| | | | (Test Number 2) | | | |
| 0 | Ambient | 500 | 500 | 200 | 300 | 100 |
| 130 | 107 | 250 | | | | |
| 195 | 121 | | off | | | |
| 280 | 249 | 400 | - | | | |
| 292 | 271 | 500 | - | | | |
| 302 | 293 | 600 | - | | | |
| 343 | 391 | 750 | - | | | |
| 350 | | END OF | TEST (Test Aborted) | | | |
| | | | (Test Number 3) | | | |
| 0 | Ambient | 500 | 500 | 200 | 300 | 100 |
| 80 | 110 | 250 | | | | |
| 95 | 121 | | off | | | |
| 234 | 260 | 500 | - | | | |
| 264 | 316 | 750 | - | | | |
| 329 | 454 | 1000 | - | | | |
| 357 | 538 | off | - | | | |
| 410 | | | END OF TEST | | | |

## Table 5

## POWER CONSUMPTION

(Continued)

| Elapsed Test Time (minutes) | Incinerator Temperature ($^oC$) | Incinerator Heater Power (watts) | Afterburner Heater Power (watts) | Tape Heater Power (watts) | Motor Power Paddle Blade Rotation (watts) | $O_2$ Sensor, Miscellaneous Power (watts) |
|---|---|---|---|---|---|---|
| | | | (Test Number 4) | | | |
| 0 | Ambient | 500 | 500 | 200 | 300 | 100 |
| 78 | 121 | | off | | | |
| 80 | 127 | 250 | - | | | |
| 220 | 260 | 500 | - | | | |
| 250 | 316 | 750 | - | | | |
| 307 | 454 | 1000 | - | | | |
| 340 | 538 | off | - | | | |
| 397 | | | END OF TEST | | | |
| | | | (Test Number 5) | | | |
| 0 | Ambient | 500 | 500 | 200 | 300 | 100 |
| 84 | 121 | | off | | | |
| 180 | 316 | 750 | - | | | |
| 235 | 454 | 1000 | - | | | |
| 267 | 538 | off | - | | | |
| 318 | | | END OF TEST | | | |

## Table 6

## ENERGY CONSUMPTION

| Test Number | Incinerator Heaters (kwhr) | Afterburner Heaters (kwhr) | Other (kwhr) | Total (kwhr) |
|---|---|---|---|---|
| 1 | 3.085 | 1.150 | 4.400 | 8.635 |
| 2 | 2.369 | 1.625 | 3.500 | 7.494 |
| 3 | 2.838 | .792 | 4.100 | 7.730 |
| 4 | 2.763 | .650 | 3.970 | 7.383 |
| 5 | 2.721 | .700 | 3.180 | 6.601 |

This is true primarily because an increasingly more significant portion of the power for heating is consumed purely in heating the subsystem itself for smaller waste loads.

However, for comparative purposes, the motor power for rotation of the paddle blade assembly should really be increased to 600 watts for Test Number 1, reflecting the increase in motor size most likely required to maintain satisfactory rotation with a full waste load. This would increase energy consumption for this test by 2.200 kwhr to 10.835 kwhr for the test time recorded. Total energy consumption figures for Test Numbers 3, 4, and 5 are less than this figure by 29%, 32%, and 39%, respectively.

Based on a total energy consumption figure of 10.8 kwhr for the subsystem operating with a full waste load, together with energy consumption during warm-up equal to .800 kwhr, daily energy consumption for the subsystem would be somewhat less than 2.0 kwhr per man.

### 3.5 Prorated Oxygen Consumption

The consumption of oxygen per gram of waste solids for each of the five tests is summarized in Table 7. This table has been formulated on the basis that for each test the feces contained 25% solids and the urine distillate residue contained 50% solids. The input solids for each test were therefore 686 gm for Test Number 1, 695 gm for Test Number 2, and 348 gm for the remaining three tests.

The high value of oxygen consumption for Test Number 3 is most likely due to processing of residual wastes remaining within the incinerator after the first two tests.

The values of total oxygen supplied in Table 7 are approximately twice the equivalent values reported in Reference 2. This increase in oxygen requirement is most likely due to more complete processing of the wastes

during the five tests as a result of their break-up within the incinerator. (The tests reported in Reference 2 were performed without mechanical break-up of the wastes.)

Table 7

OXYGEN CONSUMPTION PER GRAM OF WASTE SOLIDS

| Test Number | Oxygen Supplied to Afterburner (gm) | Oxygen Supplied to Incinerator (gm) | Total Oxygen Supplied (gm) | Oxygen in Exhaust Gas (gm) | Total Oxygen Consumed (gm) |
|---|---|---|---|---|---|
| 1 | .76 | .28 | 1.04 | .11* | .93 |
| 2** | .66 | -- | .66 | .24 | .42 |
| 3 | .98 | .41 | 1.39 | .21 | 1.18 |
| 4 | .84 | .33 | 1.17 | .35 | .82 |
| 5 | .82 | .33 | 1.15 | .28 | .87 |

* Gas collection incomplete due to leakage in gas collection envelope.

** Test aborted during pyrolysis at an incinerator temperature of 410°C.

## Section 4

## CONCLUSIONS AND RECOMMENDATIONS

### 4.1 Conclusions

On the basis of the test results obtained during Task II, the following conclusions can be made concerning the design, operation, and performance of the baseline integrated waste incineration subsystem.

1. The conclusions reached at the end of Task I (Reference 3) leading to the design of the baseline subsystem remain basically unchanged. However,

1a. It should be added that a paddle blade assembly rotational speed of 300 rpm is not only necessary for adequate shearing of the waste materials during waste loading and creating a sufficient centrifugal force field for retainment purposes, but it is also necessary for preventing formation of hard chunks of waste materials during pyrolysis.

1b. Location of the transport air blower downstream of the subsystem is not desirable for two reasons. First, the restriction imposed on the air flow by the catalyst bed prevents the attainment of an adequate flow rate for satisfactory pneumatic transport of waste materials into the incinerator. Second, cooling of the catalyst bed by this air flow could lead to the production of unsterile end products.

1c. While filtering of the exhaust gases and vapors emanating from the incinerator is required, the catalytic afterburner should not be used to perform this function. The afterburner provides inadequate filtering (small amounts of fine black particulates were found in the condensate after each test). In addition, ash build-up at the inlet to the afterburner, in particular on the catalyst retaining screen, can lead to blockage of gas flow through the subsystem and subsequent pressurization significantly above ambient.

1d. While the catalytic afterburner appears to be of suitable size and configuration for use in the subsystem, external cooling is required during pyrolysis to maintain safe operating temperature levels within the afterburner. This requirement is in addition to the requirement for oxygen introduction to the afterburner through a supply fitting arrangement such as that used for the last three tests in the test series.

2. The motor power provided to rotate the paddle blade assembly is inadequate for maintaining a rotational speed of 300 rpm during pyrolysis of the typical daily waste load anticipated from six men. It is adequate for half this waste load.

3. Since the proportional controller in the oxygen supply line to the catalytic afterburner was not used, verification of satisfactory oxidation within the afterburner with this arrangement was not made. However, manual control of the oxygen flow to the afterburner in response to variations in the oxygen concentration in the afterburner exhaust gas was readily carried out once incinerator heating rates were used which did not produce excessive afterburner oxygen demands. In particular, large or rapid fluctuations in oxygen demand were not observed as long as the phenomenon of chunk break-up within the incinerator was avoided.

4. Results of the analyses of the output ash,condensate, and gas collected after each test (particularly for the last three tests) compare favorably with similar results documented in Reference 2.

5. Based on the energy consumed by the baseline subsystem during the test series, it is estimated that daily energy consumption by the subsystem would be about 2.0 kwhr per man.

6. Oxygen consumption per gram of waste solids was approximately one gram, or twice the value reported in Reference 2.

## 4.2 Recommendations

Based on the observations and conclusions drawn from Task II, it is apparent that the design of the baseline integrated waste incineration subsystem should be revised in a number of areas.

1. The motor power provided to rotate the paddle blade assembly should be doubled to allow proper processing of the typical daily waste load anticipated from six men.

2. The transport air blower should be connected to the subsystem between the incinerator and catalytic afterburner, thereby allowing the transport air flow to bypass the afterburner.

3. Methods of filtering the exhaust gases and vapors emanating from the incinerator prior to their entrance into the catalytic afterburner should be investigated and the most promising technique incorporated into the design of the subsystem.

4. Methods of cooling the catalytic afterburner in a controlled fashion during pyrolysis should also be investigated and the most promising technique incorporated into the design of the subsystem.

It is recommended that an extensive series of laboratory tests be conducted with the design of the baseline subsystem revised as outlined above. These tests would provide a large and meaningful set of data which would permit subsystem performance, especially with regard to long-term operation, to be thoroughly investigated and which would also permit proper operational procedures to be fully established.

It is further recommended that (1) some of these tests be performed with different catalysts in an effort to obtain the most satisfactory output products possible and (2) some of these tests be conducted with waste load compositions which include plastics typically found in spacecraft wastes.

## REFERENCES


1. Hurley, T. L., Rollo, E. J., and Remus, G. A., "Study for Evaluation of Incineration and Microwave Treatment of Human Fecal Matter for Spacecraft Operation", NASA CR 73247, 1968.

2. Labak, L. J., Remus, G. A., and Krug, E. K., "Experimental Study and Design, Fabrication and Testing of an Incineration System for Human Wastes", NASA CR 114279, 1970.

3. Fields, S. F., Labak, L. J., and Honegger, R. J., "Development of an Ingegrated, Zero-G Pneumatic Transporter/Rotating-Paddle Incinerator/ Catalytic Afterburner Subsystem for Processing Human Wastes on Board Spacecraft-Component Performance Summary", NASA CR 114763, 1974.

# Appendix A

## BASELINE INTEGRATED WASTE INCINERATION SUBSYSTEM: OPERATIONAL SPECIFICATION

Based on the results of Task I and on the conclusions drawn from these results, an operational specification for a baseline integrated waste incineration subsystem was prepared and included in the report documenting work under that task (Reference 3). The operational specification is repeated here for continuity, beginning in Section A.1. The operational specification is divided into the following categories: purpose, mode of operation, configuration, performance requirements, operating constraints, sequence of operations, and primary specifications.

### A.1 Operational Specification

#### A.1.1 Purpose

The baseline integrated waste incineration subsystem shall collect, transport, and convert solid and liquid human wastes into innocuous, sterile end products. It shall be capable of processing, on a cyclic basis, the typical daily waste load anticipated from six men:

| | | |
|---|---|---|
| Human Feces (25% solids) | 900 grams | (2.0 pounds) |
| Urine Distillate Residue (50% solids) | 900 grams | (2.0 pounds) |
| Rinse Water | 320 grams | (0.7 pounds) |
| Toilet Tissue and Liners | 45 grams | (0.1 pounds) |
| TOTAL WEIGHT | 2165 grams | (4.8 pounds) |

### A.1.2 Mode of Operation

Human wastes shall be collected in a waste transport tube fitted with a disposable liner and transported pneumatically to an incineration unit in which the solid wastes shall be physically reduced in size and the entire waste mass converted to vapors, gases, and an inorganic ash.

The wastes -- including the liner and used toilet tissue -- shall be retained within the incinerator through the action of an artificial force field created by a rotating paddle arrangement within the incinerator. All transport and generated gases and vapors shall be discharged from the central rotational axis.

Conversion of the wastes shall take place in three steps as follows:

1. Boil-off of volatiles and water by heating from ambient temperature through 100°C (212°F),
2. Pyrolysis (thermal destruction in the absence of oxygen) of the dehydrated residue by heating from 100°C (212°F) to 540°C (1000°F), and
3. Final combustion with oxygen of the carbonaceous pyrolysis residue at 540°C (1000°F) to 650°C (1200°F).

The generated gases and vapor shall pass first through a catalytic afterburner maintained at 370-480°C (700-900°F) for further processing with oxygen and then through a condenser for the collection of all condensible vapors. The final inorganic ash shall be removed from the incinerator to storage by reverse air flow through the incinerator into an ash collector.

### A.1.3 Configuration

The baseline integrated subsystem configuration shall be as depicted in Figure A1. The subsystem shall consist of a waste transport tube, incineration unit, catalytic afterburner, oxygen controller, condenser, blowers, and

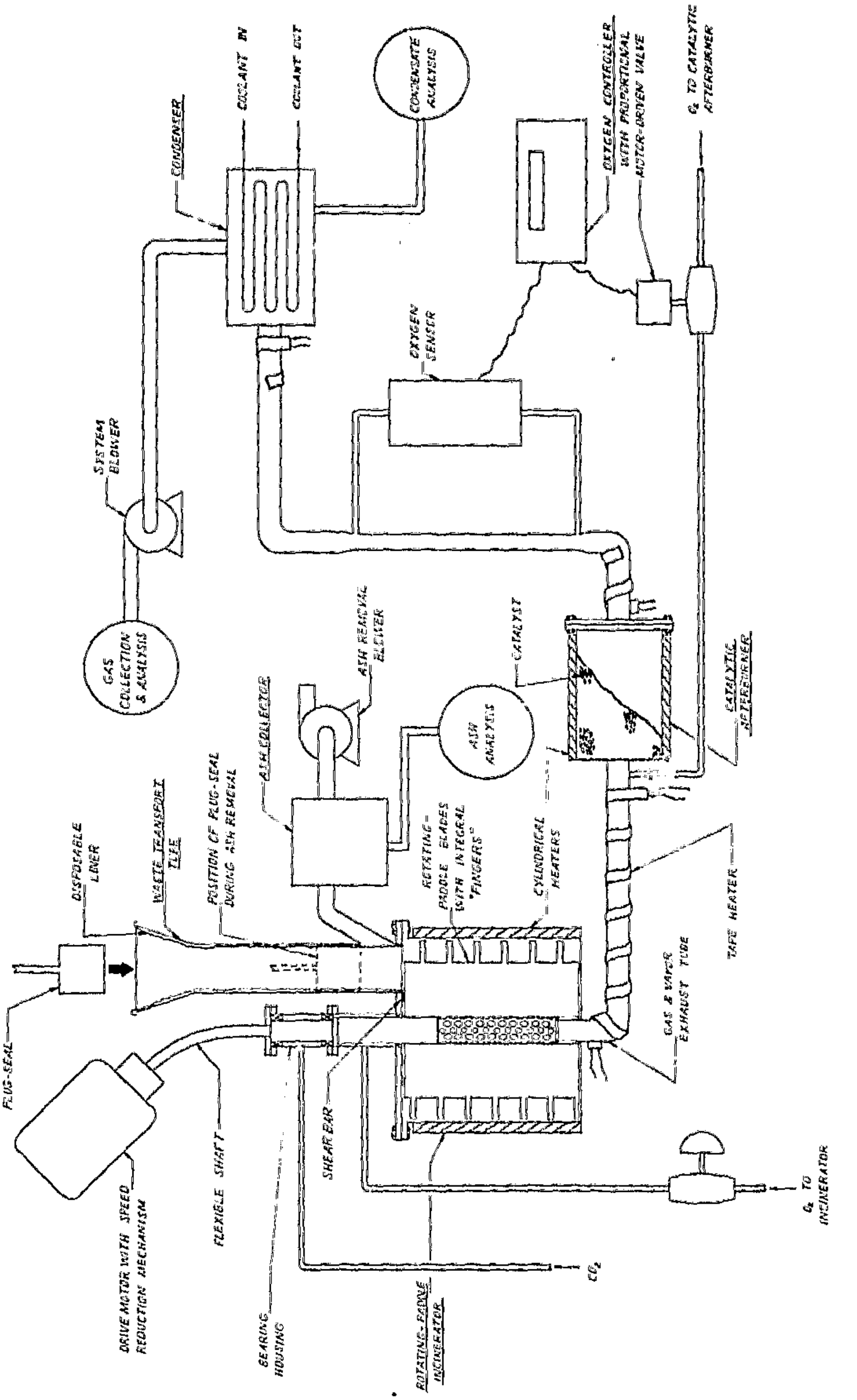



Figure A1 BASELINE INTEGRATED WASTE INCINERATION SUBSYSTEM

necessary interconnecting piping, valves, thermocouples, gauges, controls, wiring, and insulation for proper operation of the subsystem.

Waste Transport Tube - The waste transport tube shall be cylindrical -- 6.4-cm (2-1/2-in) ID, 30.5-cm (12-in) length, stainless steel -- and fitted at its inlet end with an 11.4-cm (4-1/2-in) diameter stainless steel waste acceptance funnel. The tube and funnel shall be fully lined with a suitable disposable liner material exhibiting the following features:

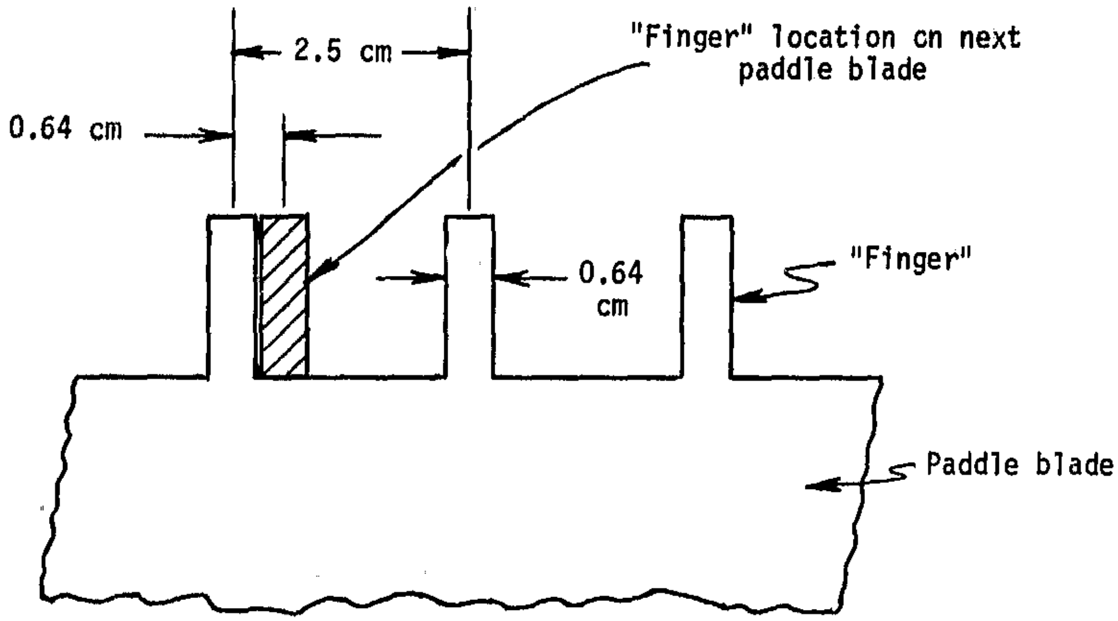
- Nonabsorbent (water-resistant or water-repellent)
- Resistant to oils and greases
- Easily torn or shredded
- Combustible with no objectionable off-gases
- Lightweight and flexible

The waste transport tube shall be permanently attached to the incinerator and shall accept a Hastelloy-X plug to seal the waste transport tube during processing of the wastes. This plug/seal shall be inserted into the tube inlet manually after the collection of a waste load.

The waste transport tube shall also be fitted with a 1.9-cm (3/4-in) ID stainless steel take-off tube located at the intersection of the waste transport tube and the incinerator and positioned 30° to the waste transport tube axis to provide for final ash removal from the incinerator.

Incineration Unit - The incineration unit shall be a cylindrical shell -- 20.6-cm (8-1/8-in) OD, 21.6-cm (8-1/2-in) length, 0.16-cm (0.063-in) wall thickness, Hastelloy-X -- fitted externally with cylindrical electrical resistance heaters and embedded within suitable insulation. The waste transport tube shall be attached to the incinerator on the main detachment flange adjacent to the incinerator wall and parallel to its central axis.

The inner volume of the incinerator shall contain a rotating assembly consisting of a 3.5-cm (1-3/8-in) OD Hastelloy-X central tube located along the axis of the incinerator and fitted with four 0.24-cm (0.093-in) thick Hastelloy-X paddle blades; these blades shall be permanently attached along the length of the tube and shall be at right angles to each other. Each paddle blade shall be 6.4 cm (2-1/2 in) wide and fitted along its outermost edge with seven 0.64-cm (1/4-in) wide "fingers", which shall extend to within 0.16 cm (1/16 in) of the inside wall of the incinerator. The "fingers" shall be made integral with the paddle blades and shall be positioned 2.5 cm (1 in) apart on a blade and 0.64 cm (1/4 in) from the adjacent "finger" on the next blade as depicted in the following drawing.




Within the incinerator, the central rotating tube shall contain a large number of 0.64-cm (1/4-in) diameter holes through its wall to permit discharge of the transport and generated gases. This tube shall be rotated by an external 1/2-horsepower electrical motor fitted with a flexible drive shaft to

provide a maximum paddle blade rotational speed of 350 rpm. The rotational drive shaft shall be common with the central tube and shall be contained within two roller bearings located within a sealed housing attached to the main detachment flange of the incinerator. The drive shaft/central tube shall penetrate the main detachment flange of the incinerator through a labyrinth seal having clearance gaps of 0.013 cm (0.005 in) or less.

The incinerator end plate shall be 0.24-cm (0.093-in) thick Hastelloy-X and fitted at its center with a 2.5-cm (1-in) OD Hastelloy-X gas and vapor exhaust tube. This tube shall penetrate into the center of the rotating central tube for a maximum distance of 7.6 cm (3 in); it shall not touch the rotating tube. The opposite end of this exhaust tube shall be connected to the inlet end plate of the catalytic afterburner; the overall length of the tube shall not be less than 10.2 cm (4 in) or more than 15.2 cm (6 in). The exhaust tube shall be wrapped with an electrical tape heater and embedded within suitable insulation.

The main detachment flange of the incinerator shall be 0.64-cm (1/4-in) thick Hastelloy-X and bolted to the incinerator shell; a spiral-wound stainless steel/asbestos gasket shall be used to seal this flange. A Hastelloy-X cutting mechanism shall be provided within the incinerator at the intersection of the waste transport tube and the main detachment flange.

Catalytic Afterburner - The catalytic afterburner shall be a cylindrical shell -- 9.5-cm (3-3/4-in) OD, 16.5-cm (6-1/2-in) length, 0.08-cm (0.032-in) wall thickness, Hastelloy-X -- fitted externally with cylindrical electrical resistance heaters and embedded within suitable insulation. It shall contain approximately 1200 gm (2.65 lb) of catalyst consisting of 0.32-cm (1/8-in) diameter by 0.32-cm (1/8-in) long cylindrical alumina pellets coated with 0.5% palladium. Hastelloy-X fine mesh screens shall be fitted above and below the catalyst bed to prevent loss of the catalyst.

The catalytic afterburner shall be fitted with a 0.64-cm (1/4-in) thick Hastelloy-X detachment flange fitted at its center with a 1.9-cm (3/4-in) OD Hastelloy-X exhaust tube, which shall be connected at its other end to a condenser. This exhaust tube shall contain two tee's to provide a 1.0-cm (3/8-in) OD Hastelloy-X gas sample line. The sample line shall pass through a Thermo-Lab "Thermox" WDG Oxygen Sensor to monitor the oxygen concentration of the final exhaust gas. The signal from the sensor shall go to a Thermo-Lab "Thermox" WDG Analyzer, whose amplified signal shall go to an API Model 228-21 Double Output, 2-Mode Controller. This controller shall signal an API Model 5001 Current/Position Converter, which shall operate a Barber-Coleman Proportional Motorized Operator, which, in turn, shall drive an oxygen valve feeding oxygen to the catalytic afterburner.

Other Components - Other components in the subsystem shall include a condenser and a properly sized blower located downstream of the condenser. This blower shall provide the necessary air flow for pneumatic transport of the waste materials into the incinerator and shall provide for continuous removal of vapors and gases generated during processing of the wastes.

A second blower shall be provided for the removal of the final inorganic ash from the incinerator. This blower shall be located downstream of an ash collector attached to the ash removal tube previously described.

Miscellaneous components shall include, but shall not be limited to, thermocouples, recorders, temperature controllers, pressure/vacuum gauges, and flow meters.

### A.1.4 Performance Requirements

Waste Transport Tube

- Must accept whole fecal matter and used toilet tissue and allow pneumatic transport of these materials to the incinerator.

- Must not physically plug with wastes
- Must not allow isolated stray waste particles to collect outside of the liner
- Must be easily cleaned after use or kept clean during use

Incineration Unit

- Must reduce size of whole waste materials and protective liner to be readily accepted by rotating paddle blades
- Must confine all liquids and solids within the annular space between the inside wall and the rotating paddle blades
- Must completely reduce wastes to vapors, gases, and an inorganic ash
- Must completely sterilize all waste particles
- Must accept pneumatic transport gas flow
- Must allow for complete discharge of transport and generated gases and vapors without the loss of liquid or solid particles
- Must not leak solids, liquids, or gases into drive tube housing
- Must allow for adequate removal of the final inorganic ash by reverse air flow
- Must provide for adequate oxygen distribution during final combustion step

Catalytic Afterburner

- Must accept flow rate of transport and generated gases and vapors
- Must oxidize all unoxidized gases and vapors
- Must physically filter any entrained particulates from the incinerator exhaust gas

- Must provide sterilization of low-temperature volatiles and water vapor

### A.1.5 Operating Constraints

Waste Transport Tube

- Must operate between waste acceptance funnel at ambient temperature and incinerator up to 650°C (1200°F)
- Transport gas flow must entrain all waste materials and transport them to the incinerator with no detrimental build-up of back pressure and no contamination of tube walls
- Transport gas flow rate must be minimum feasible

Incineration Unit

- Must operate between ambient temperature and 650°C (1200°F)
- Must exhaust all transport and generated gases and vapors to catalytic afterburner
- Must not drive gases and vapors back into waste transport tube or into bearing housing
- Must accept whole waste materials and adequately reduce their size
- Must operate under both reducing and oxidizing atmospheres

Catalytic Afterburner

- Must operate continuously at 370-480°C (700-900°F)
- Must prevent generated gases and vapors from short-circuiting through the catalyst bed
- Must operate continuously under a strong oxidizing atmosphere

A.1.6 Sequence of Operations

During operation of the waste incineration subsystem, the following operations will be performed continuously:

- Rotation of the entire paddle blade assembly
- Bleeding of an inert gas (carbon dioxide) into the bearing housing at a prescribed flow rate for cooling of the bearings and positive pressure differential across the labyrinth seal
- Heating of the catalytic afterburner to 370-480°C (700-900°F)
- Heating of the exhaust tubes to a minimum of 260°C (500°F)
- Monitoring of the oxygen concentration of the exhaust gas from the catalytic afterburner and maintaining a minimum of 5% oxygen in this gas
- Operation of the transport and vapor removal blower
- Operation of the downstream vapor condenser

Upon activation of the entire integrated subsystem, a preformed disposable liner will be inserted into the waste transport tube and clamped in place at the waste acceptance funnel inlet. Whole wastes and toilet tissue will be deposited in the funnel and pneumatically transported into the incinerator where they will be reduced in size by the cutting mechanism. The macerated wastes will then be distributed uniformly within the annular region between the rotating paddle blades and incinerator wall. The "fingers" will continuously rake through the waste mass to keep it from sticking and caking on the incinerator wall.

After the addition of wastes equivalent to that generated daily by six men, the prescribed amount of urine distillate residue and rinse water will be supplied through the waste transport tube. The disposable liner will then be released, and the plug/seal brought into position.

The incinerator heaters will then be activated at the prescribed power input to begin the thermal reduction process. When the waste mass remaining in the incinerator attains a temperature of 540°C (1000°F) as sensed by a thermocouple, the incinerator heaters will be shut off, and oxygen will be admitted at a prescribed flow rate to the bearing housing, downstream of the bearings. When all oxidizable materials have been oxidized within the incinerator, the oxygen concentration in the final exhaust gas will increase, and the oxygen controller will shut all heaters and all oxygen flows off. After the necessary cool-down, the ash removal blower will then be activated, and the plug/seal will be positioned to clear the opening to the ash removal tube; ash will then be "vacuumed" from the incinerator for a prescribed period of time, after which the entire subsystem will be shut down.

### A.1.7 Primary Specifications

| | |
|---|---|
| Waste Transport Tube: | 6.4 cm (2-1/2") ID x 7.0 cm (2-3/4") OD x 30.5 cm (12") long, 316 L S.S. |
| Waste Acceptance Funnel: | Tapered, 11.4 cm (4-1/2") dia. x 6.4 cm (2-1/2") dia. x 10.2 cm (4") long, 316 L S.S. |
| Plug/Seal: | 6.4 cm (2-1/2") dia. x 6.4 cm (2-1/2") long, Hastelloy-X |
| Liner Material: | 20# White #84600 M.G. Kraft with 4# Waxsorb (Thilmany Paper Company) or equivalent |
| Cutting Mechanism: | Shear bar, 0.64 cm (1/4") wide x 19.4 cm (7-5/8") long, Hastelloy-X |

| | |
|---|---|
| Incinerator Shell: | Cylindrical, 20.6 cm (8-1/8") OD x 0.16 cm (0.063") wall x 21.6 cm (8-1/2") long, Hastelloy-X |
| Incinerator Exhaust End Plate: | 20.6 cm (8-1/8") dia. x 0.24 cm (0.093") thick, Hastelloy-X |
| Incinerator Main Detachment Flange: | 29.8 cm (11-3/4") dia. x 0.64 cm (1/4") thick, Hastelloy-X |
| Incinerator Flange Bolts: | 1.0 cm (3/8")-16NC x 2.5 cm (1") long, 316 S.S. on 22.9 cm (9") b.c. |
| Central Rotating Shaft/Tube: | 3.5 cm (1-3/8") OD x 0.11 cm (0.045") wall, Hastelloy-X |
| Paddle Blades: | 6.4 cm (2-1/2") wide x 20.3 cm (8") long x 0.24 cm (0.093") thick, with 7 integral "fingers", Hastelloy-X (4) |
| "Fingers": | 0.64 cm (1/4") wide x 1.8 cm (11/16") long x 0.24 cm (0.093") thick, integral with paddle blade, Hastelloy-X (28) |
| Incinerator Heaters: | Model 50821 Quarter Cylindrical (Lindberg Hevi-Duty) around shell (4), Model 50116 Flat (Lindberg Hevi-Duty) on end plates (2) |
| Incinerator Main Flange Gasket: | Spiral-wound, 316 S.S./asbestos, 20.8 cm (8-3/16") ID x 21.7 cm (8-17/32") OD (Flexitallic Gasket Co.) |

| | |
|---|---|
| Rotational Drive Motor: | 1/2-HP, 1725 rpm, with SCR adjustable speed control, 115 V, 60 Hz (Dayton Manufacturing Company) |
| Speed Reduction Mechanism: | Model S-133-MC56-5-A "Uniline", right-angle, 5:1 reduction ratio (Ohio Gear Company) |
| Motor Coupling to Drive Tube: | Model 50FC flexible coupling (Stow Manufacturing Company) |
| Bearings: | Model JH2016 cylindrical roller bearings (2) (Torrington Manufacturing Company) |
| Bearing Housing: | Cylindrical, 3.5 cm (1-3/8") ID x 0.16 cm (1/16") wall x 12.7 cm (5") long, 316 L S.S. |
| Gas Exhaust Tube: | 2.5 cm (1") OD x 0.12 cm (0.048") wall, Hastelloy-X |
| Catalytic Afterburner: | Cylindrical, 9.5 cm (3-3/4") OD x 0.08 cm (0.032") wall x 16.5 cm (6-1/2") long, Hastelloy-X |
| Catalytic Afterburner Detachment Flange: | 12.7 cm (5") dia. x 0.64 cm (1/4") thick, Hastelloy-X |
| Catalyst: | 0.5% palladium on 0.32 cm (1/8") dia. x 0.32 cm (1/8") long cylindrical alumina pellets, 1200 gm (2.65 lb) (Englehard Industries, Inc.) |
| Catalytic Afterburner Heaters: | Model 50411 Half Cylindrical (Lindberg Hevi-Duty) around shell (2) |

| | |
|---|---|
| Oxygen Concentration Sensing System: | Model WDG "Thermox" sensor, Model WDG "Thermox" analyzer (Thermo-Lab Instruments) |
| Oxygen Control System: | Model 228-21 double output, 2-mode controller with Model 5001 current/position converter (LFE-API Instruments); Model 35-569 proportional motorized operator (Barber-Coleman); and suitable valve |
| Condenser (lab only): | Vacuum collection bottles cooled with dry ice/acetone, sized to accept anticipated vapor flow rates |
| Main Pneumatic Transport & Operational Blower: | Centrifugal-type, sized to accept anticpated gas flow rates |
| Ash Removal Blower & Ash Collector: | Vacuum cleaner (Kirby Manufacturing Company) or equivalent |
| Thermocouples: | Model SS-188-K-9 (Claud S. Gordon) |
| Line Tape Heaters: | Model S-40854-10 (Sargent-Welch Scientific Company) |

# Appendix B

## DESIGN DRAWINGS

The preceding operational specification for a baseline integrated subsystem was translated into a set of eleven detailed design drawings for subsystem fabrication and assembly. This set of drawings is presented in Figures B1 through B11.

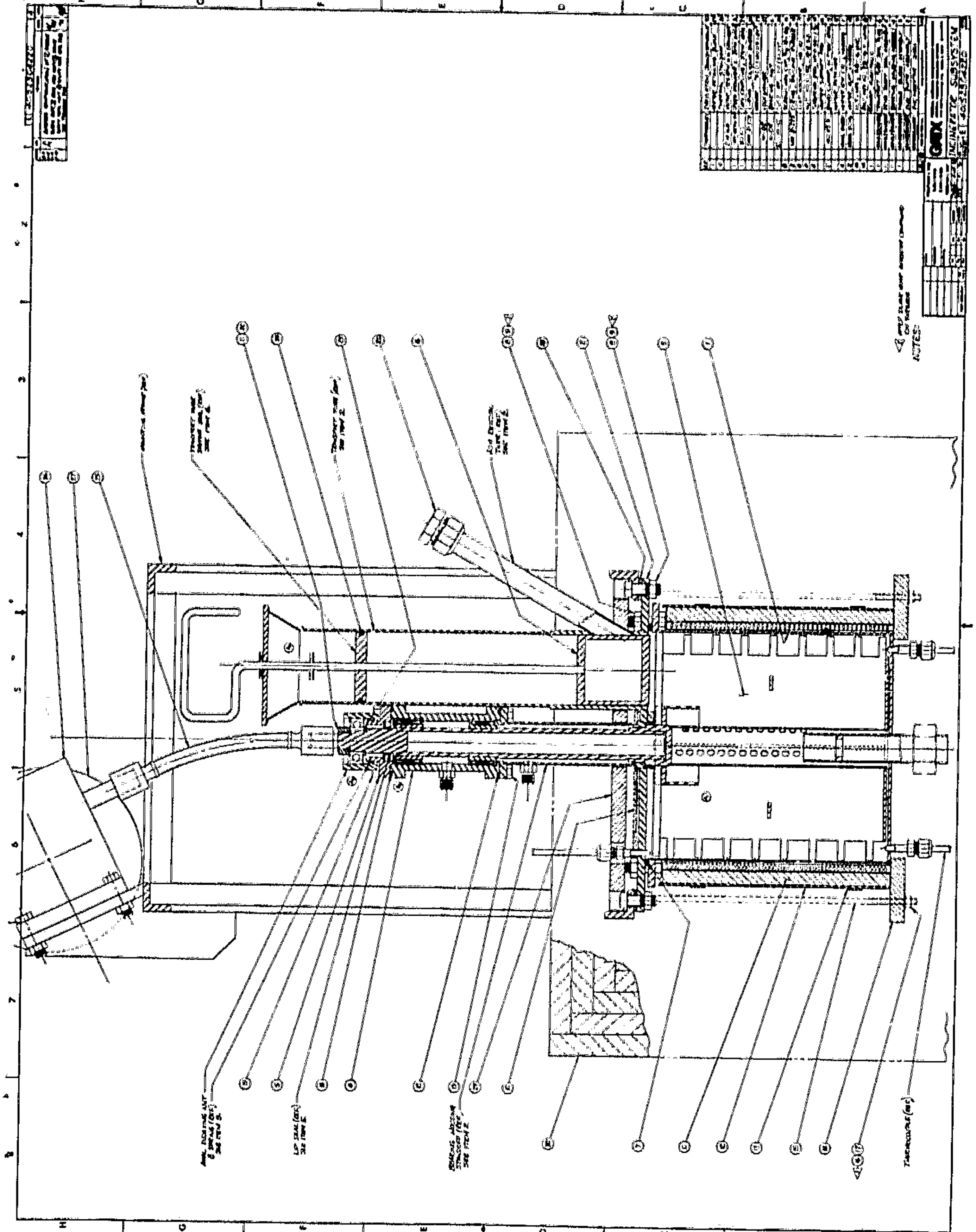


Figure B1 INCINERATOR SUBSYSTEM

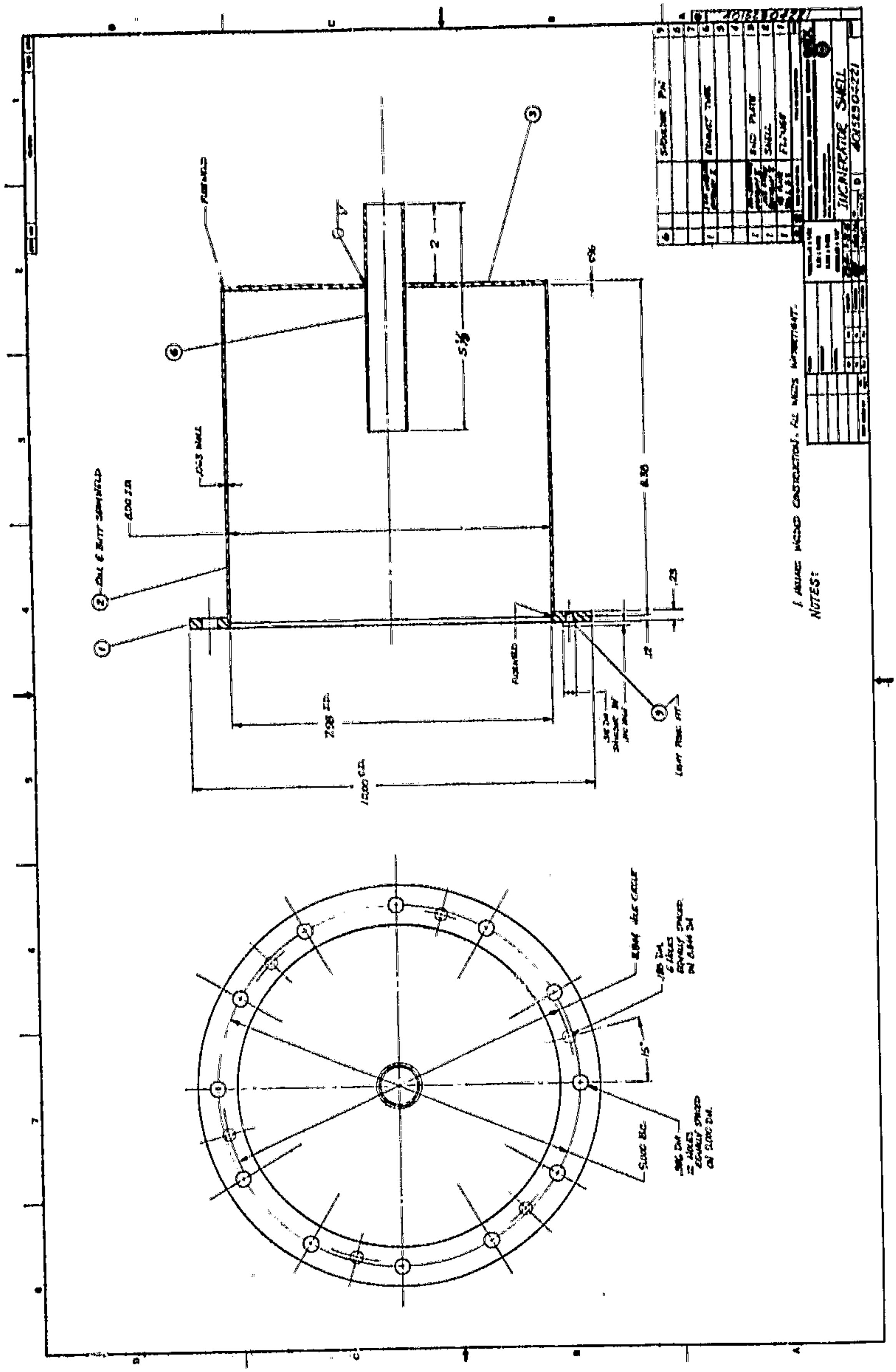



Figure B2 INCINERATOR SHELL

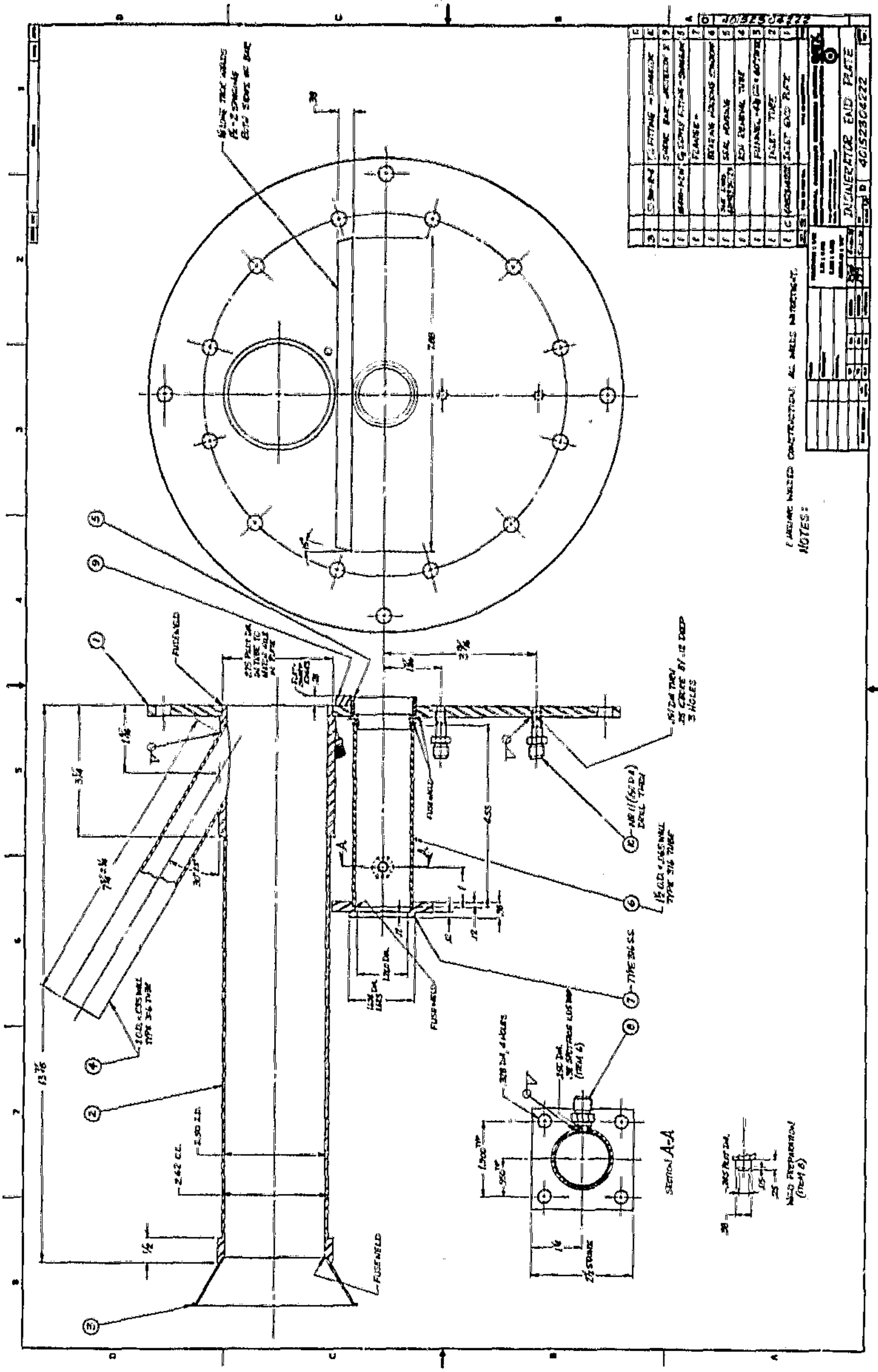



Figure B3 INCINERATOR END PLATE

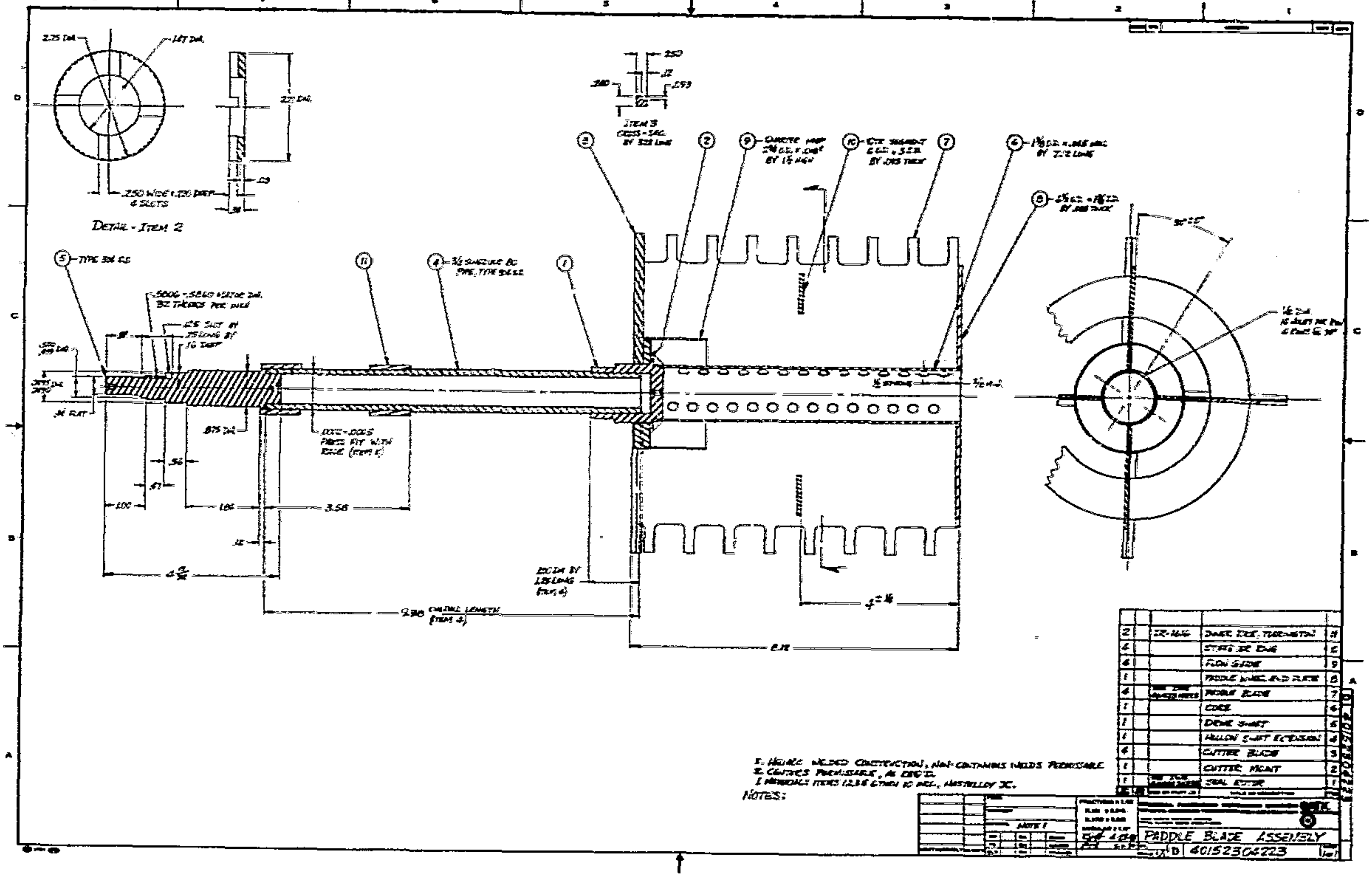



Figure B4 PADDLE BLADE ASSEMBLY

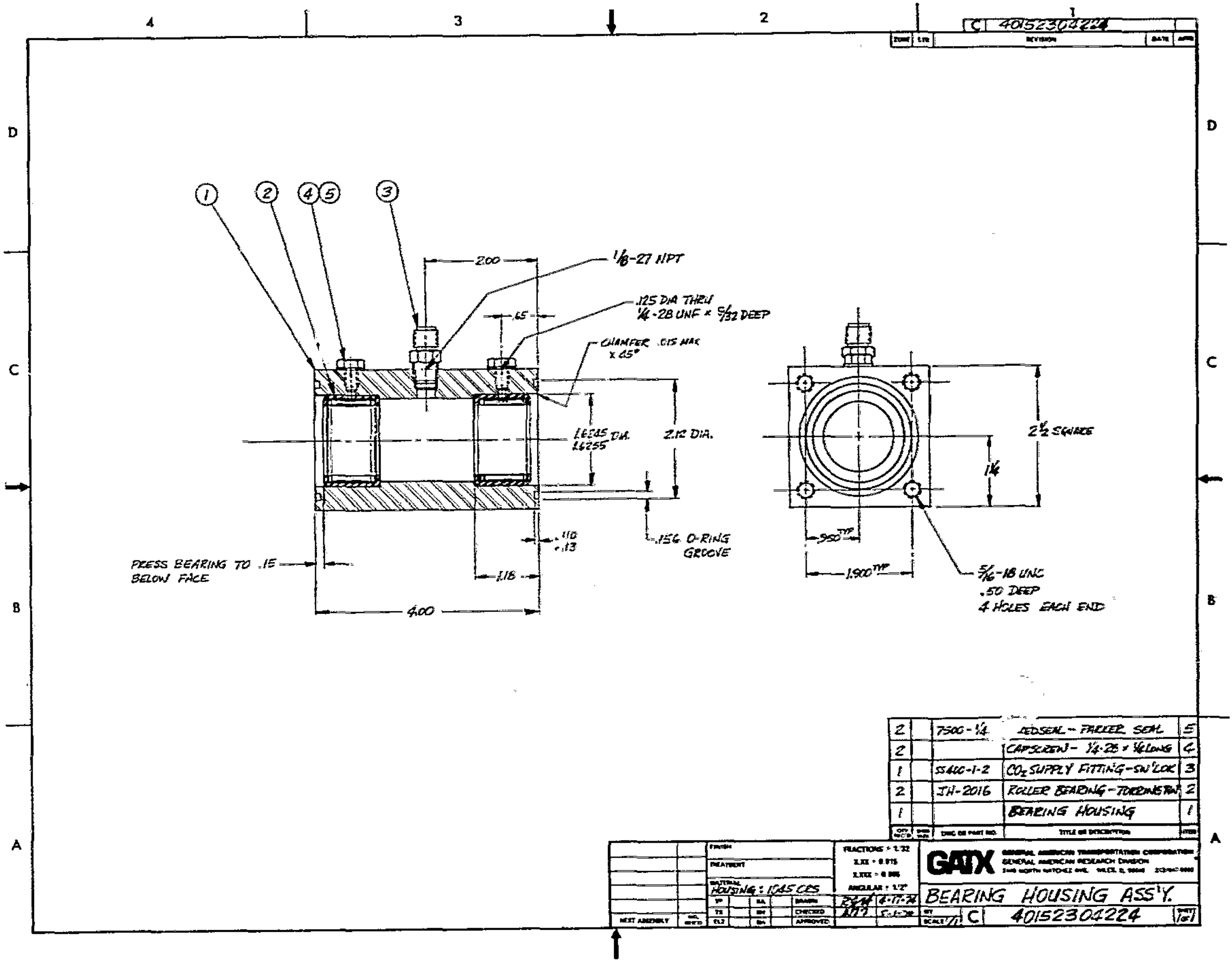



Figure B5 BEARING HOUSING ASSEMBLY

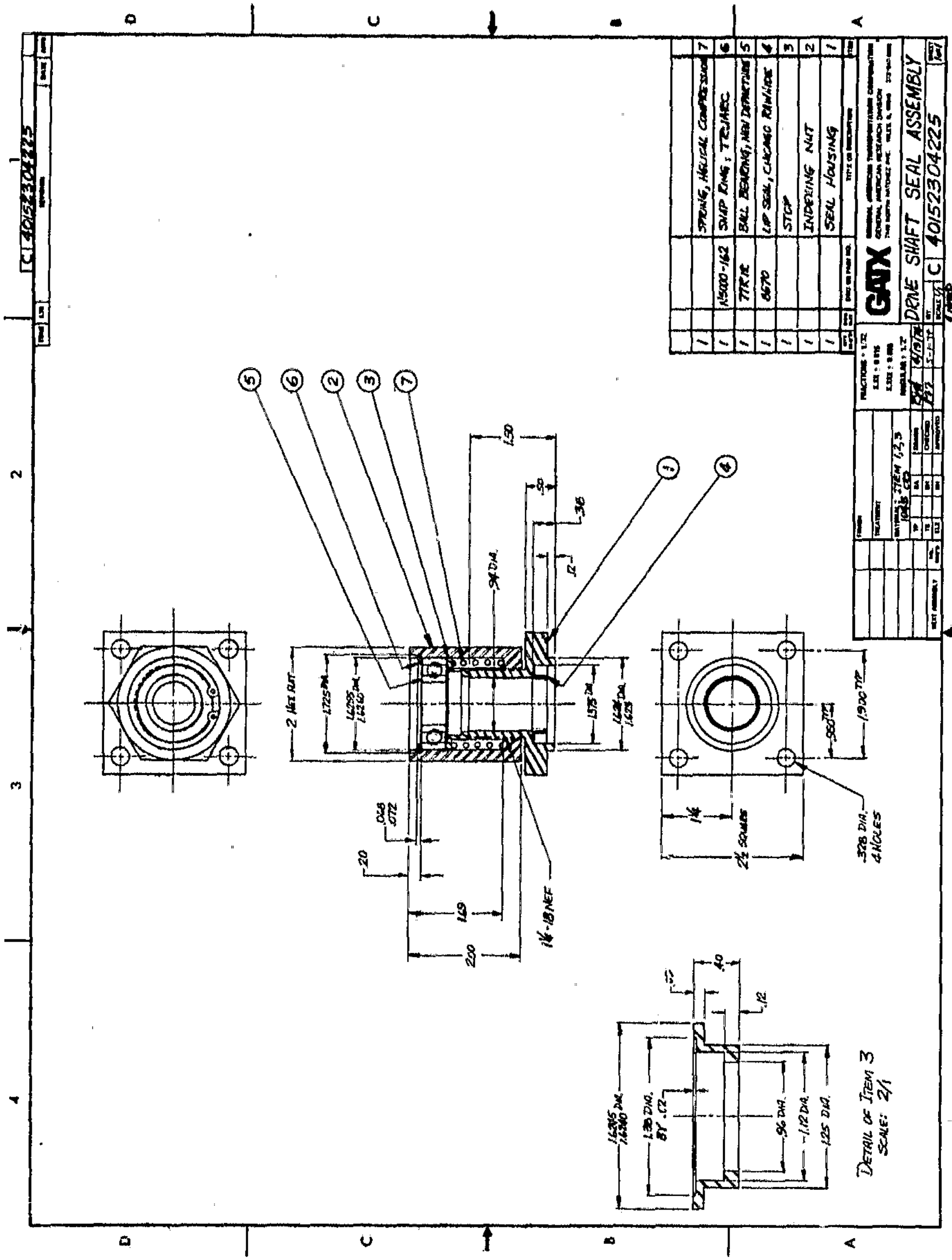



Figure B6 DRIVE SHAFT SEAL ASSEMBLY

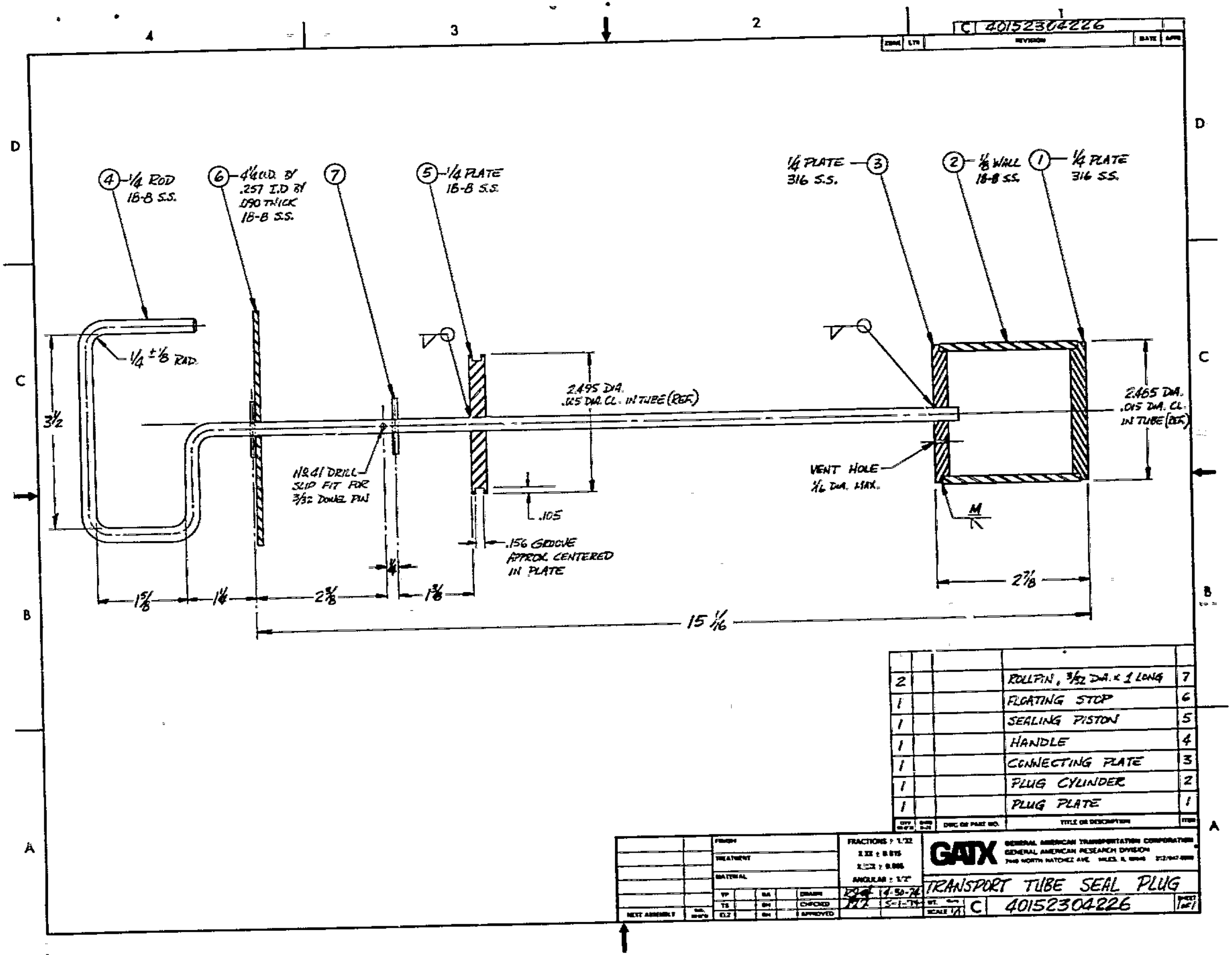



Figure B7 TRANSPORT TUBE SEAL PLUG

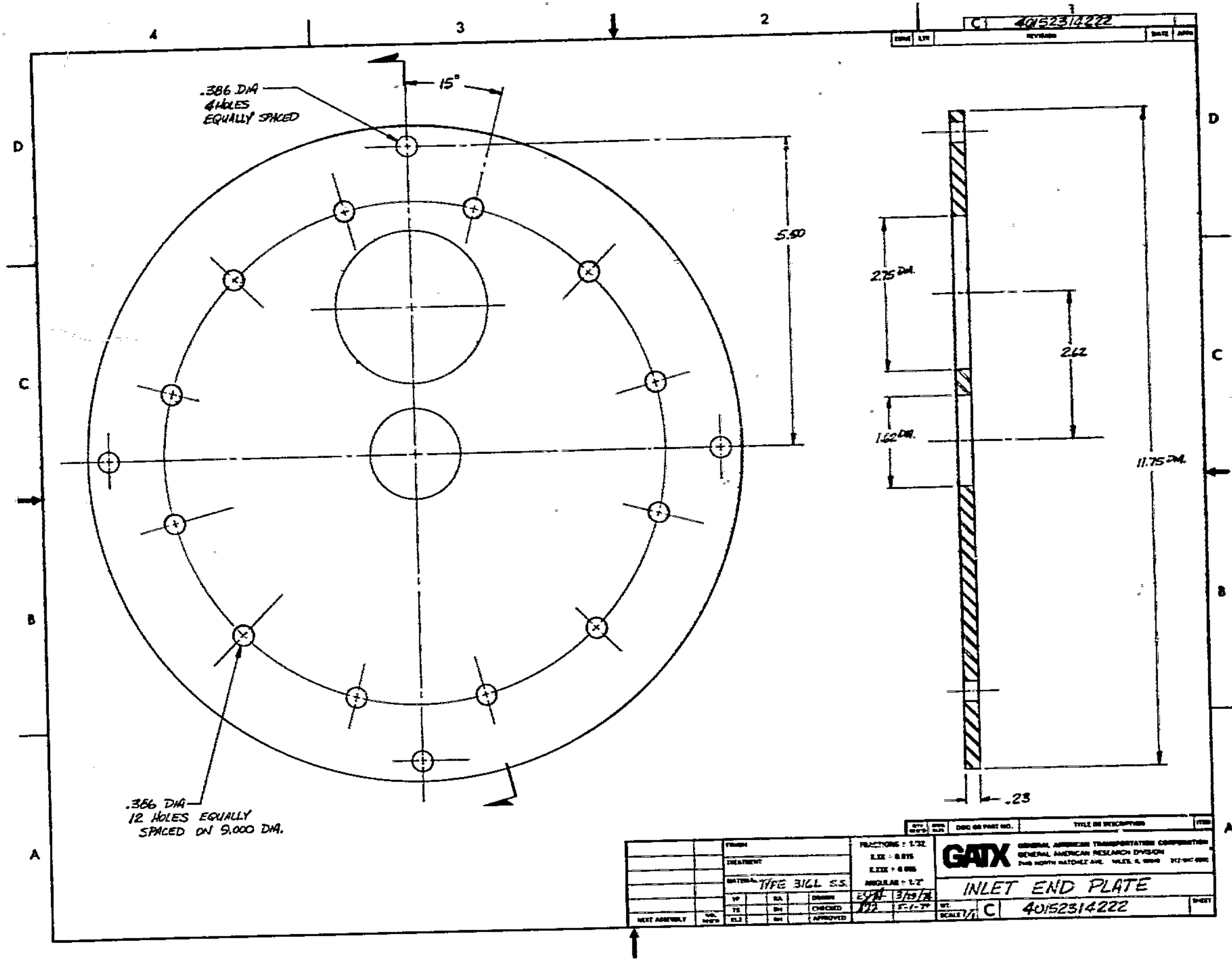



Figure B8 INLET END PLATE

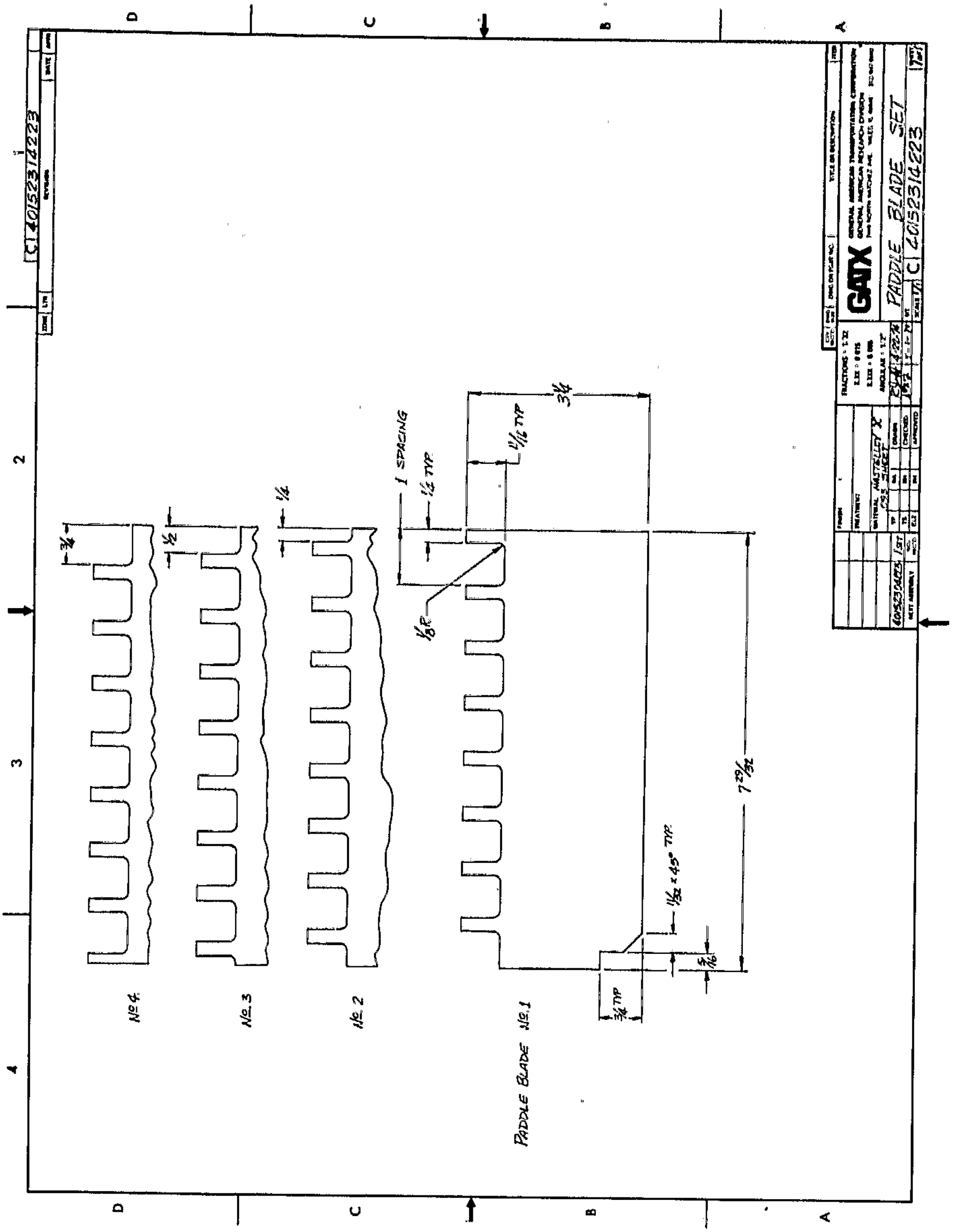



Figure B9 PADDLE BLADE SET

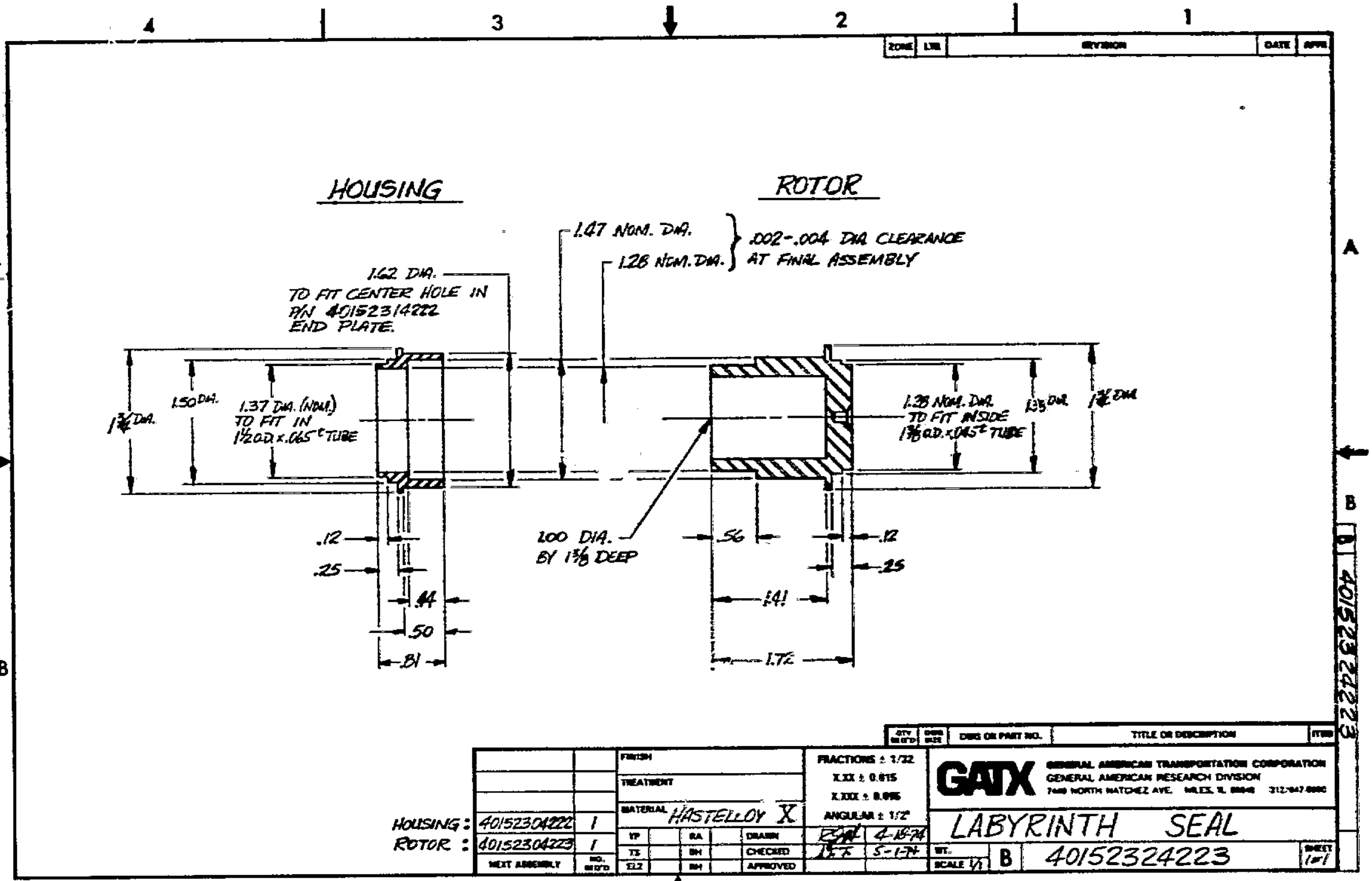



Figure B10 LABYRINTH SEAL

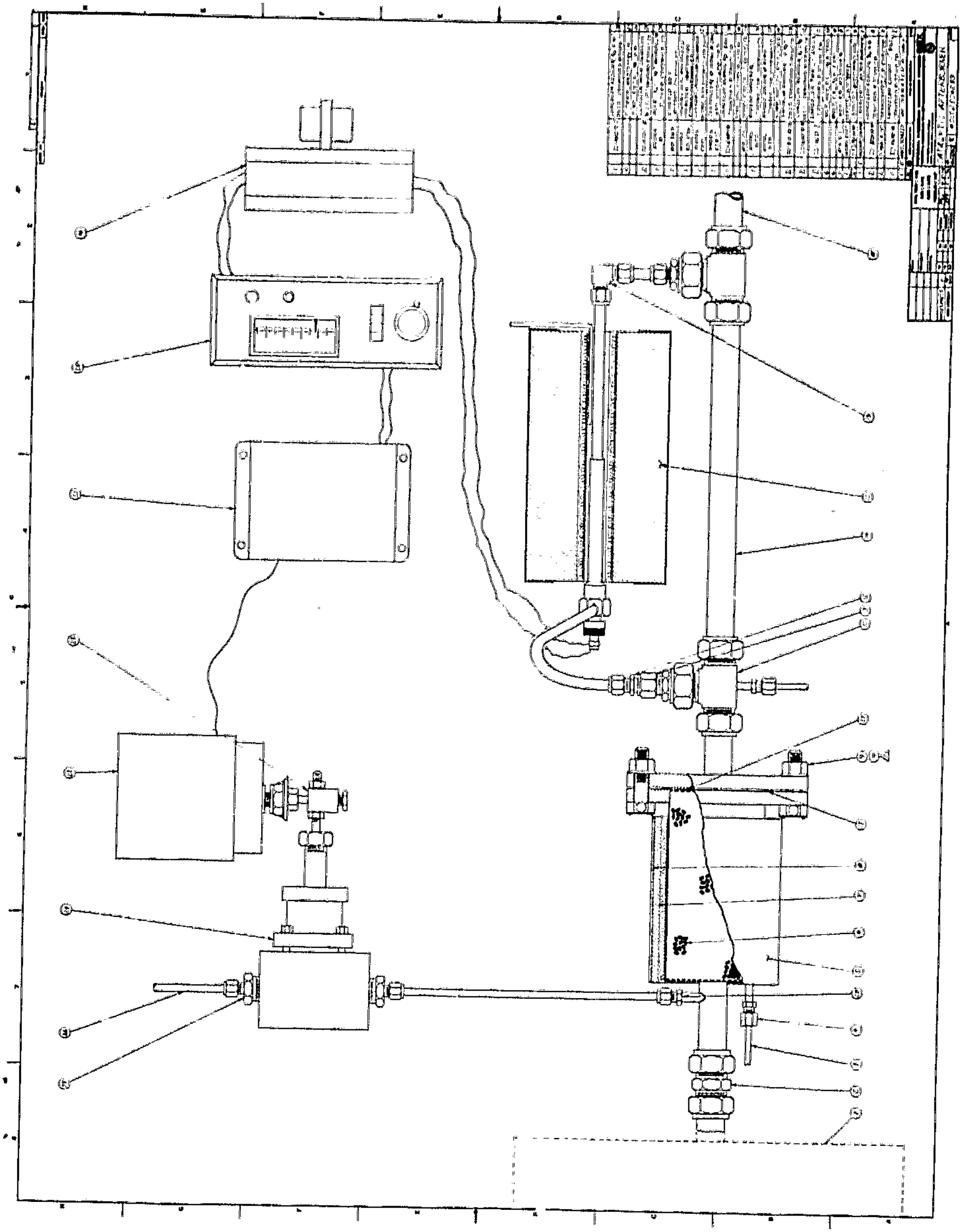


Figure B11 CATALYTIC AFTERBURNER SUBSYSTEM